JOURNAL OF AGRICULTURAL RESEARCH

VOL. 61 WASHINGTON, D. C., NOVEMBER 15, 1940 No. 10

EFFECT OF ENVIRONMENTAL FACTORS ON THE TRANSPIRATION AND GROWTH OF TOMATO PLANTS[1]

By ARTHUR C. FOSTER, *senior pathologist*, and EVERETT C. TATMAN, *assistant scientific aide, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

It is generally held that the transpiration rate of plants is largely determined by the environmental factors that surround the plant, but there is still much uncertainty concerning the very large loss of water through transpiration.

The factors that affect the rate of movement of water from the soil into the plant, the upward movement within the plant, and the ultimate dissipation as vapor into the surrounding air are all fully discussed in a voluminous literature that is readily available. The effects of environment on transpiration have been studied by Alexandroff (*1*),[2] Briggs and Shantz (*2*, *3*, *4*), Burgerstein (*5*, *6*), Clapp (*7*), Curtis (*8*), Dixon (*9*), Iljin (*11*), Kiesselbach (*12*), Lloyd (*13*), Maximov (*14*), Miller (*15*), Snow (*18*), Sresnevski (*19*), Udolskaja (*20*), and others. However, there appear to be few data recorded in the literature concerning the effect on the transpiration rate of the exhaustion of soil nutrients and the consequent retardation of the growth of the plant. Furthermore, it is apparent that considerable misleading data have been used for interpreting the facts relating to this problem. Data have appeared which indicate that plants grown in soils low in nitrogen, as compared with those grown in soils high in nitrogen, consistently have the higher transpiration ratio (quantity of water transpired per gram of aerial dry matter formed) and also the higher transpiration rate (amount of water lost in absolute units per unit of leaf area per unit of time); and these data have been used as a basis for illogical interpretation of the facts. This paper presents the results of studies that show why the interpretation is incorrect.

METHODS AND MATERIALS

CULTURAL CONDITIONS

All data to be presented were collected from experiments previously reported by the writers (*10*). The experiments were conducted in the greenhouses at the Arlington Experiment Farm, Arlington, Va., during 1934. The tomato plants were grown in a good greenhouse compost soil consisting of loam from Arlington farm, manure, and muck, with which sand was later mixed to improve water penetration and distribution. The water-retaining capacity of this soil remained uniform at 65 percent of its dry weight throughout the study.

The plants were grown at soil-moisture levels of approximately 38, 47, and 56 percent of the weight of the soil, representing 59, 72, and 86 percent of the moisture-holding capacity, respectively. The rate of

[1] Received for publication August 5, 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 719.

water loss for each plant was recorded daily. At the same time efforts were made to maintain the above-mentioned soil-moisture levels by frequent (4 to 6 times daily) replacement of water lost as indicated by weighing the cultures on solution balances of 20- to 40-kg. capacity. The soil surface of each culture was covered with a close-fitting disk of waterproof paper to reduce evaporation losses.

The plants were grown in glazed 3-gallon crocks, without drainage, holding 12 kg. of soil. The fertilizers were mixed with the soil at the rate of 2 tons per acre as it was placed in the crocks. The fertilizer formulas used were 12–0–12, 12–6–12, and 6–12–6, the figures in each representing percent of nitrogen, phosphoric acid, and potash, respectively. A series of check cultures received no fertilizer.

In each of the three temperature units of the greenhouse (66°, 70°, and 74° F.) and each of the three moisture levels at each temperature, the following cultures were set up: Five crocks of each of two fertilizer treatments, six crocks of the third treatment, and three unfertilized checks. Thus, at each of the 36 points of observation there were 3 to 6 replicate cultures, giving a total of 171 plants under moderately well controlled environments.

The plants (Marglobe variety) were pruned to a single stem, tied to bamboo stakes and topped just above the sixth flower cluster.

GROWTH HABIT AND RESPONSE OF TOMATO PLANTS TO ENVIRONMENT

The plants used in these experiments were similar to those grown under field conditions. They were mature and large, with heavy, thick foliage, and they bore a good crop of fruit. In the high-temperature unit (74° F.) the plants were tall and slender with relatively small stems and long internodes; they were succulent and of the spindling type. In the medium-temperature unit (70°) the plants were shorter, the stems were heavier, and the leaves were spaced closer together. In the lowest temperature unit (66°) the plants were still shorter, had dense green foliage, and many showed the strongly vegetative type of growth.

TEMPERATURE AND HUMIDITY

It was intended to operate the greenhouse units at 75°, 70°, and 65° F., respectively, from the beginning of the experiment, September 10, but high outside temperature made it impossible to keep the units at these temperatures until about the first week in October. For the duration of the experiment the average weekly mean temperatures were 74.3°, 70.4°, and 65.7° in units 1, 2, and 3, respectively. From October 2 to December 17, during which period better temperature control could be maintained, the averages of the weekly means were 74.6°, 69.1°, and 62.9°, respectively.

The averages of weekly mean relative humidities of units 1, 2, and 3 for the entire period were 55.3, 60.0, and 63.1 percent, respectively. This order of difference unavoidably existed throughout the period regardless of the seasonal temperature, since there was no available means of raising the moisture content of the air introduced from outside incidental to ventilation and temperature control.

ATMOMETER INDEX

In table 1 the atmometer readings for the different temperature units are given. There appear to be considerably larger differences

between the black and white atmometers in the higher temperature units than in the lower ones. These differences can be explained if the concept of Sresnevski (*19*) is accepted; he reported that such differences must be proportional to the deficit of saturation.

TABLE 1.—*Corrected daily average atmometer readings on a weekly basis from three temperature units, 1934*

Period ended	Daily average atmometer evaporation from—							
	Unit 1 (74° F.)[1]				Unit 2 (70° F.)		Unit 3 (66° F.)	
	Black	White	Black	White	Black	White	Black	White
	Ml.	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*
Sept. 24	21.2	14.4	20.6	14.5	19.5	15.1	18.8	14.5
Oct. 1	21.1	14.6	21.0	15.1	19.6	15.4	19.4	15.0
Oct. 8	18.0	12.6	18.4	13.1	16.1	12.9	15.9	12.6
Oct. 15	25.5	18.3	26.2	19.0	22.9	18.0	22.4	18.0
Oct. 22	20.8	15.5	22.0	15.9	18.8	15.3	18.2	14.6
Oct. 29	19.7	15.6	20.4	15.4	16.2	14.0	14.9	12.6
Nov. 5	21.0	15.5	20.1	14.6	17.5	14.4	15.5	12.7
Nov. 12	20.5	16.3	21.5	15.7	15.4	13.3	13.1	11.4
Nov. 19	19.7	16.0	20.3	16.1	16.5	14.3	14.4	12.8
Nov. 26	15.2	11.9	16.3	12.5	12.7	11.3	11.1	10.1
Dec. 3	11.7	9.2	12.0	9.3	7.8	7.4	6.3	5.9
Dec. 10	18.8	14.7	18.7	14.3	14.8	13.7	12.3	11.1
Dec. 17	22.9	18.8	22.2	18.5	17.9	17.0	14.7	14.0
Average	19.7	14.8	19.9	14.9	16.5	14.0	15.1	12.7

[1] Two sets of atmometers installed.

STATISTICAL ANALYSIS OF DATA

The data were analyzed statistically by the analysis of variance method as adapted by Snedecor (*16*, *17*), and all significant differences were based on the generalized error. Differences required for significance between means of treatments and single treatments were calculated when the error appeared to be homogeneous. Significant differences are indicated by odds of 19:1 at the 5-percent level of *t;* highly significant differences are indicated by odds of 99:1 at the 1-percent level of *t*. Also, in tables 2 to 7, inclusive, the third and fourth decimals have been rounded off in the customary way.

EXPERIMENTAL RESULTS

To gain a better conception of the responses of the tomato plants grown under different environmental conditions, a large number of data were collected bearing upon water requirement, total water transpired, final dry weight of aerial parts, fruit yield, and starch content of stem and leaf parts of the plants from the different cultures, all of which are essential for an adequate interpretation of the data on daily amounts of water transpired, presented later in this paper.

EFFECT OF ENVIRONMENT ON WATER REQUIREMENT OF THE TOMATO

The term "water requirement" of plants has been used by many investigators to express the ratio between water absorbed (or water expenditure) and dry matter produced. However, in the data presented in table 2 this term is used in the same sense in which it was employed by Briggs and Shantz (*2*, *3*, *4*), to indicate the milliliters of water transpired per gram of gain in dry weight of aerial vegetative parts of plants in the several environments. It is well known that many factors may influence the water requirement of plants, which varies widely with different species.

TABLE 2.—*Effect of soil moisture, soil nutrients, and temperature on the water requirement of tomato plants, Sept. 18 to Dec. 23, 1934*

[Data based on weighted averages of 3 to 6 plants in each culture]

EXPERIMENTAL DATA

Soil moisture [1] (percent)	Fertilizer formula (N–P–K)	Water requirement [2] at—			
		74° F.	70° F.	66° F.	Mean
		Ml.	*Ml.*	*Ml.*	*Ml.*
59	12–0–12	579	450	317	448.7
	12–6–12	559	398	302	419.7
	6–12–6	572	491	446	503.0
	Check	668	632	535	611.7
	Mean	594.5	492.8	400.0	495.8
72	12–0–12	629	493	409	510.3
	12–6–12	620	472	366	486.0
	6–12–6	678	535	452	555.9
	Check	721	648	551	640.0
	Mean	662.0	537.0	444.5	547.8
86	12–0–12	694	558	445	565.7
	12–6–12	685	547	438	556.7
	6–12–6	721	618	486	608.3
	Check	786	721	590	699.0
	Mean	721.5	611.0	489.8	607.4
Mean	12–0–12	634.0	500.3	390.3	508.2
	12–6–12	621.3	472.3	368.7	487.4
	6–12–6	657.0	548.0	461.3	555.4
	Check	725.0	667.0	558.7	650.2
	Mean	659.3	546.9	444.8	550.3

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Ml.	*Ml.*
Between single cultures	58.8	82.4
Between means of 3 cultures	34.0	47.6
Between means of 4 cultures	29.4	41.2
Between means of 9 cultures	19.6	27.5
Between means of 12 cultures	17.0	23.8

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	14,624
Between moisture	2	[3] 37,465
Between temperature	2	[3] 138,243
Between fertilizer	3	[3] 47,197
Total interactions	28	673
Moisture × temperature	4	510
Moisture × fertilizer	6	390
Temperature × fertilizer	6	[4] 1,681
Remainder (error)	12	364

[1] Percentage of water-retaining capacity.
[2] Milliliters of water per gram of dry weight of tops.
[3] Significant with odds greater than 99:1.
[4] Significant with odds greater than 19:1 but less than 99:1.

The data given in table 2 show the highly significant effects of soil moisture, temperature, and soil nutrients on the water requirement of

the tomato plants in the respective cultures. The mean value of 650.2 for the check plants under all conditions was significantly different from the 6–12–6 mean of 555.4, the 12–6–12 mean of 487.4, and the 12–0–12 mean of 508.2. (See table 2 for differences required for significance at odds of 19:1 and 99:1.) A statistical interpretation of these data indicates quite definitely that the unfertilized group of plants, consistently and uniformly, had the highest water requirement for the entire growth period under all environments studied. Furthermore, these data appear to indicate that the rate of transpiration of the unfertilized check plants averaged higher than that of any of the fertilized groups of plants during the entire growth period.

As is shown by the data in table 2, variations in environmental conditions, such as are determined by fertilizer, soil moisture, humidity, and air temperature, may cause a wide variation in the expenditure of water by plants. Low soil moisture and low air temperature have great influence in reducing the water consumption per gram of dry material produced; furthermore, increasing amounts of nitrogen along with potash promote greater efficiency in water utilization. Increasing the soil moisture results in more extravagant use of water by the plants. It is significant that in these studies plants without added fertilizer were found to be the most extravagant users of water under all cultural conditions. This has long been a misinterpreted phenomenon. It has misled investigators into assuming that there was no change in the relative rate of transpiration of the check plants when soil nutrients were exhausted, or at any stage of their growth. It is also important to note that the 12–0–12 fertilizer cultures expended slightly larger amounts of water than did the 12–6–12 cultures. This fact will be illustrated in more detail in figures 2 to 11, to be presented later.

EFFECT OF ENVIRONMENT ON TOTAL WATER TRANSPIRED

The data given in table 3 show the marked influence of environment on the total amount of water transpired by the tomato plants in the different cultures during the 96-day period, September 18 to December 23, 1934. The difference required for significance between means of nine plant cultures at odds of 99:1 was 3.06 liters. The total water transpired by the check plant cultures with mean of 53.30 liters of water was highly significant, and greater than the 6–12–6 mean of 48.18 liters, the 12–6–12 mean of 39.71 liters, and the 12–0–12 mean of 41.44 liters. Further study of the analysis of variance shows a highly significant interaction of moisture $\times$ temperature and temperature $\times$ fertilizer, as measured from the generalized error. The magnitude of differences between individual plant cultures is also apparent.

EFFECT OF ENVIRONMENT ON DRY WEIGHT

Table 4 gives data showing the effect of environment on the total dry weight of tomato plants grown in the different cultures. Since these plants were topped after the appearance of the sixth flower cluster and since all axillary growth was removed promptly as it appeared, the final dry weights of the plants in the different cultures were in fairly close agreement except where indicated by the data in table 4. It is important to note that there were no significant differences in dry weight between the means of the check plants at different

temperatures except the 66.46 mean at 59 percent soil moisture, but that there were interactions between moisture × fertilizer with odds greater than 99:1.

TABLE 3.—*Effect of soil moisture, soil nutrients, and temperature on the total water transpired by tomato plants, Sept. 18 to Dec. 23, 1934*

[Data based on weighted averages of 3 to 6 plants in each culture]

EXPERIMENTAL DATA

Soil moisture (percent) [1]	Fertilizer formula (N–P–K)	Water transpired at—			
		74° F.	70° F.	66° F.	Mean
		Liters	*Liters*	*Liters*	*Liters*
59	12–0–12	24.1	23.3	21.9	23.07
	12–6–12	25.3	20.8	19.6	21.91
	6–12–6	31.3	27.6	28.8	29.20
	Check	43.3	39.6	38.5	40.45
	Mean	30.99	27.80	27.17	28.65
72	12–0–12	43.4	39.4	35.7	39.49
	12–6–12	41.9	38.5	38.8	39.74
	6–12–6	54.5	49.2	46.5	50.03
	Check	65.5	54.8	49.3	56.49
	Mean	51.31	45.45	42.55	46.44
86	12–0–12	71.9	60.4	53.1	61.78
	12–6–12	66.3	54.1	52.1	57.49
	6–12–6	72.3	61.0	62.7	65.33
	Check	71.5	58.8	58.6	62.97
	Mean	70.48	58.57	56.64	61.89
Mean	12–0–12	46.45	40.99	36.89	41.44
	12–6–12	44.52	37.81	36.81	39.71
	6–12–6	52.66	45.90	46.00	48.18
	Check	60.08	51.06	48.78	53.30
	Mean	50.93	43.94	42.12	45.66

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Liters	*Liters*
Between single cultures	6.55	9.17
Between means of 3 cultures	3.77	5.30
Between means of 4 cultures	3.27	4.58
Between means of 9 cultures	2.18	3.06
Between means of 12 cultures	1.89	2.65

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	249.4928
Between moisture	2	[2] 3,319.9205
Between temperature	2	[2] 259.4527
Between fertilizer	3	[2] 353.7813
Total interactions	28	18.2914
Moisture × temperature	4	[2] 30.8991
Moisture × fertilizer	6	[2] 50.9000
Temperature × fertilizer	6	4.8218
Remainder (error)	12	4.5193

[1] Percentage of water-retaining capacity.
[2] Significant with odds greater than 99:1.

TABLE 4.—*Effect of soil moisture, soil nutrients, and temperature on the total dry weight of tomato plants, 1934*

EXPERIMENTAL DATA

[Data based on weighted averages of 3 to 6 plants in each culture]

Soil moisture (percent) [1]	Fertilizer formula (N-P-K)	Dry weight of plants at—			
		74° F.	70° F.	66° F.	Mean
		Gm.	*Gm.*	*Gm.*	*Gm.*
59	12-0-12	41.6	51.7	68.9	54.05
	12-6-12	45.4	52.3	64.9	54.19
	6-12-6	54.6	56.1	64.6	58.42
	Check	64.8	62.7	71.9	66.46
	Mean	51.60	55.69	67.56	58.28
72	12-0-12	69.0	79.8	87.3	78.74
	12-6-12	67.7	81.7	105.8	85.04
	6-12-6	80.3	91.9	102.8	91.69
	Check	90.8	84.8	89.4	88.35
	Mean	76.97	84.55	96.34	85.95
86	12-0-12	103.6	108.2	119.4	110.41
	12-6-12	96.7	98.9	118.8	104.82
	6-12-6	100.2	98.7	129.2	109.35
	Check	90.9	81.5	99.4	90.63
	Mean	97.87	96.84	116.71	103.80
Mean	12-0-12	71.42	79.90	91.88	81.07
	12-6-12	69.92	77.63	96.50	81.35
	6-12-6	78.39	82.22	98.85	86.49
	Check	82.19	76.34	86.91	81.81
	Mean	75.48	79.02	93.54	82.68

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Gm.	*Gm.*
Between single cultures	15.3	21.4
Between means of 3 cultures	8.82	12.37
Between means of 4 cultures	7.64	10.76
Between means of 9 cultures	5.10	7.14
Between means of 12 cultures	4.41	6.19

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	485.6897
Between moisture	2	[2] 6,313.1643
Between temperature	2	[2] 1,098.2169
Between fertilizer	3	58.8553
Total interactions	28	71.4219
Moisture × temperature	4	29.1270
Moisture × fertilizer	6	[2] 191.6844
Temperature × fertilizer	6	73.0185
Remainder (error)	12	24.5906

[1] Percentage of water-retaining capacity.
[2] Significant with odds greater than 99:1.

EFFECT OF ENVIRONMENT ON FRUIT YIELD

Yield of fruit was affected somewhat markedly by the different environments, as is indicated by the data given in table 5. The fruit yield from the check plants was significantly smaller than that from any of the fertilized group of plants, except at 59 percent soil moisture, at odds greater than 99 : 1. The analysis of variance indicates the highly significant effect of soil moisture, temperature, and fertilizer on the yield of fruit from the plants in the different cultures; also, the

interaction of soil moisture × fertilizer was highly significant. Optimum conditions for fruit yield appeared to be 70° F. and 86 percent soil moisture. The magnitude of difference in yield of fruit due to treatment is large enough to be apparent even between individual treatments. These data are given to indicate the amounts of water required by developing fruit.

TABLE 5.—*Effect of soil moisture, soil nutrients, and temperature on the average yield of green fruit per tomato plant, 1934*

EXPERIMENTAL DATA

Soil moisture (percent) [1]	Fertilizer formula (N-P-K)	Weight of fruit per plant at—			
		74° F.	70° F.	66° F.	Mean
		Gm.	*Gm.*	*Gm.*	*Gm.*
59	12-0-12	658	826	533	672.3
	12-6-12	603	825	576	668.0
	6-12-6	1,072	1,088	1,087	1,082.3
	Check	1,092	1,078	1,023	1,064.3
	Mean	856.2	954.2	804.7	871.7
72	12-0-12	1,511	1,621	1,324	1,485.3
	12-6-12	1,500	1,587	1,380	1,489.0
	6-12-6	1,935	2,026	1,677	1,879.3
	Check	1,378	1,360	1,250	1,329.3
	Mean	1,581.0	1,648.5	1,407.5	1,545.7
86	12-0-12	2,238	2,238	1,820	2,098.6
	12-6-12	2,269	2,293	1,947	2,169.6
	6-12-6	2,382	2,284	2,220	2,295.3
	Check	1,520	1,528	1,393	1,480.3
	Mean	2,102.2	2,085.7	1,845.0	2,011.0
Mean	12-0-12	1,469.0	1,561.6	1,225.6	1,418.7
	12-6-12	1,457.3	1,568.3	1,301.0	1,442.2
	6-12-6	1,796.3	1,799.3	1,661.3	1,752.3
	Check	1,330.0	1,322.0	1,222.0	1,291.3
	Mean	1,513.1	1,562.8	1,352.5	1,476.1

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Gm.	*Gm.*
Between single cultures	194.7	273.0
Between means of 3 cultures	112.39	157.64
Between means of 4 cultures	97.37	136.52
Between means of 9 cultures	64.92	91.01
Between means of 12 cultures	56.22	78.82

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	299,563
Between moisture	2	[2] 3,937,249
Between temperature	2	[2] 145,042
Between fertilizer	3	[2] 344,631
Total interactions	28	45,937
Moisture × temperature	4	11,329
Moisture × fertilizer	6	[2] 189,191
Temperature × fertilizer	6	9,641
Remainder (error)	12	3,994

[1] Percentage of water-retaining capacity.
[2] Significant with odds greater than 99:1.

TABLE 6.—*Effect of soil moisture, soil nutrients, and temperature on the starch content of tomato plant stems, 1934*

EXPERIMENTAL DATA

Soil moisture (percent) [1]	Fertilizer formula (N–P–K)	Starch content of stems (on dry-weight basis) at—			
		74° F.	70° F.	60° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
59	12–0–12	1.54	2.90	8.49	4.31
	12–6–12	1.68	1.95	5.61	3.08
	6–12–6	1.59	2.42	5.56	3.19
	Check	1.27	11.55	22.87	11.90
	Mean	1.52	4.71	10.63	5.62
72	12–0–12	.61	1.67	3.11	1.80
	12–6–12	1.22	.92	2.39	1.51
	6–12–6	1.58	1.65	3.64	2.29
	Check	9.41	12.72	24.14	15.42
	Mean	3.21	4.24	8.32	5.26
86	12–0–12	.46	.58	1.09	.71
	12–6–12	1.33	2.19	2.33	1.95
	6–12–6	1.90	1.82	6.31	3.34
	Check	3.87	6.14	19.54	9.85
	Mean	1.89	2.68	7.32	3.96
Mean	12–0–12	.87	1.72	4.23	2.27
	12–6–12	1.41	1.69	3.44	2.18
	6–12–6	1.69	1.96	5.17	2.94
	Check	4.85	10.14	22.18	12.39
	Mean	2.21	3.88	8.76	4.95

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Percent	*Percent*
Between means of 9 cultures	1.36	1.91
Between means of 12 cultures	1.18	1.66

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	37.29
Between moisture	2	[3] 9.09
Between temperature	2	[3] 139.08
Between fertilizer	3	[3] 222.70
Total interactions	28	12.17
First-degree interactions	16	19.97
Remainder (error)	12	1.76

[1] Percentages of water-retaining capacity.
[2] Significant with odds greater than 19:1 but less than 99:1.
[3] Significant with odds greater than 99:1.

EFFECT OF ENVIRONMENT ON STARCH CONTENT OF STEM AND LEAVES

Large accumulation or storage of starch in the stem and leaf parts of tomato plants is usually an indication of nitrogen deficiency, of retarded metabolism and plant growth, and of the onset of a dehydration process within the plant (*10*). Table 6 gives data showing the effect of environment on the starch content of tomato plant stems.

It will be observed that significant differences between means of fertilizer treatments, of moisture treatments, and of temperatures are indicated by the high variances due to those single factors as compared with the variances due to second-degree interaction. Since this interaction (fertilizer × moisture × temperature) is heterogeneous, it is not an adequate basis for determining the magnitude of differences required for significance except for means of primary effects. Even in these instances, the limitations of the estimated magnitudes must be kept in mind and unjustified conclusions avoided. The same limitations apply with respect to the data presented in table 7, giving the starch content of the top leaves of the plant.

TABLE 7.—*Effect of soil moisture, soil nutrients, and temperature on the starch content of top leaves of tomato plants, 1934*

Soil moisture (percent) [1]	Fertilizer formula (N–P–K)	Starch content of top leaves (on dry-weight basis) at—			
		74° F.	70° F.	66° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
59	12–0–12	3.68	1.17	3.74	2.86
	12–6–12	4.12	1.14	4.72	3.33
	6–12–6	5.16	1.42	3.29	3.29
	Check	3.12	7.98	9.22	6.77
	Mean	4.02	2.93	5.24	4.06
72	12–0–12	3.79	1.33	4.84	3.32
	12–6–12	3.52	1.97	4.85	3.45
	6–12–6	5.83	2.13	7.80	5.25
	Check	13.71	11.69	17.15	14.18
	Mean	6.71	4.28	8.66	6.55
86	12–0–12	3.02	3.57	4.70	3.76
	12–6–12	2.99	2.53	5.16	3.56
	6–12–6	8.39	6.02	9.57	7.99
	Check	13.45	10.56	15.53	13.18
	Mean	6.96	5.67	8.74	7.12
Mean	12–0–12	3.50	2.02	4.43	3.32
	12–6–12	3.54	1.88	4.91	3.44
	6–12–6	6.46	3.19	6.89	5.51
	Check	10.09	10.06	13.97	11.38
	Mean	5.90	4.29	7.55	5.91

DIFFERENCES REQUIRED FOR SIGNIFICANCE

Item	Odds	
	19:1	99:1
	Percent	*Percent*
Between means of 9 cultures	1.46	2.05
Between means of 12 cultures	1.26	1.78

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Mean square
Total	35	17.83
Between moisture	2	[2] 31.77
Between temperature	2	[2] 31.79
Between fertilizer	3	[2] 128.63
Total interactions	28	3.96
First-degree interactions	16	5.41
Remainder (error)	12	2.03

[1] Percentage of water-retaining capacity.

[2] Significant with odds greater than 99:1.

To be observed in table 7 are the highly significant effects of soil moisture, fertilizer, and temperature, as indicated by the analysis of variance of the data. Furthermore, the mean of 11.38 percent of starch for the check culture was significantly higher than the mean of 5.51 percent for the 6–12–6 culture, the mean of 3.44 percent for the 12–6–12 culture, and the mean of 3.32 percent for the 12–0–12 culture, with odds greater than 99:1. The difference required for significance between means of nine plant cultures with odds greater than 99:1 was 2.05 percent of starch.

EFFECT OF CERTAIN SOIL NUTRIENTS ON THE TRANSPIRATION OF TOMATO PLANTS

The data given in table 8 show a rather marked association between exhaustion of soil nutrients and retardation of transpiration in the unfertilized plants. Apparently this was caused by changes in the metabolic processes within the plant associated with a rather gradual dehydration of the plant tissue, which is indicated by a large accumulation of starch (*10*). These data were collected from tomato-plant cultures grown in nine different environments, with 36 points of observation, as has been described. They are based on average absolute amounts of water transpired daily during 2- to 4-day periods by three unfertilized check plants and three plants receiving each specified fertilizer treatment during the last 64 days of growth, September 18 to November 21, 1934. In table 8 the absolute amounts of water transpired by the respective cultures—check, 12–0–12, 12–6–12, and 6–12–6—are given in the first four columns. The total water transpired by each group of cultures is given at the bottom of the respective tables. The ratios of the transpiration of the several fertilized cultures to that of the unfertilized check culture for the same period are given in the last three columns of table 8. Since a simple ratio of the absolute units of water transpired by the fertilized plants to the absolute units of water transpired by the unfertilized check plants over similar periods of time is being dealt with, the relative changes in these ratios from day to day indicate the rate of transpiration of the plants in the different cultures.

TABLE 8.—*Comparison of the daily transpiration of unfertilized and fertilized tomato plants grown in nine different soil environments, 1934*

[Data based on total transpiration of 3 plants in each culture at 2- to 4-day periods of the last 65 days of growth]

UNIT 1, AT 74° F.; 59 PERCENT SOIL MOISTURE

Period ended—	Water transpired from—				Transpiration ratio of—[1]		
	Unfertilized check	Plants receiving fertilizer—			Plants receiving fertilizer—		
		12–0–12	12–6–12	6–12–6	12–0–12	12–6–12	6–12–6
	Ml.	*Ml.*	*Ml.*	*Ml.*			
Sept. 21	2,930	1,800	2,080	2,200	0.614	0.710	0.751
Sept. 25	1,600	930	820	950	.581	.513	.594
Sept. 27	1,760	820	960	950	.466	.545	.540
Sept. 29	1,740	1,090	1,130	1,600	.626	.649	.920
Oct. 2	3,160	1,500	1,600	1,950	.475	.506	.617
Oct. 5	3,665	2,050	1,925	2,375	.559	.525	.648
Oct. 8	3,730	1,625	1,735	2,325	.436	.465	.623
Oct. 12	6,600	3,140	3,070	4,150	.476	.465	.629
Oct. 15	8,350	4,020	3,940	5,260	.481	.472	.630
Oct. 17	4,845	2,275	2,215	2,980	.470	.457	.615

[1] Water transpired by unfertilized check is taken as unity.

TABLE 8.—*Comparison of the daily transpiration of unfertilized and fertilized tomato plants grown in nine different soil environments, 1934*—Continued

UNIT 1, AT 74° F.; 59 PERCENT SOIL MOISTURE—Continued

Period ended	Water transpired from—				Transpiration ratio of—		
	Unfertilized check	Plants receiving fertilizer—			Plants receiving fertilizer—		
		12-0-12	12-6-12	6-12-6	12-0-12	12-6-12	6-12-6
	Ml.	*Ml.*	*Ml.*	*Ml.*			
Oct. 20	6,800	3,225	3,150	4,350	0.474	0.463	0.640
Oct. 22	4,650	2,325	2,325	3,225	.500	.500	.694
Oct. 24	5,950	3,000	2,850	4,000	.504	.479	.672
Oct. 26	3,450	1,775	1,775	2,475	.514	.514	.717
Oct. 29	5,800	3,075	3,025	4,225	.530	.522	.728
Oct. 31	4,500	2,725	2,675	3,475	.606	.594	.772
Nov. 2	6,225	4,000	4,000	5,100	.643	.643	.819
Nov. 4	4,850	3,175	3,100	3,825	.655	.639	.789
Nov. 6	3,500	2,400	2,250	2,900	.686	.643	.829
Nov. 8	5,250	3,700	3,350	4,350	.705	.638	.829
Nov. 10	5,000	3,500	3,250	3,900	.700	.650	.780
Nov. 12	4,050	2,950	2,750	3,550	.728	.679	.877
Nov. 14	5,600	4,000	3,650	4,700	.714	.652	.839
Nov. 16	3,900	3,200	2,550	3,300	.821	.654	.846
Nov. 19	8,250	6,250	5,500	7,000	.758	.667	.848
Nov. 21	5,800	4,150	3,600	4,950	.716	.621	.853
Total	121,955	72,700	69,275	90,065			
UNIT 1, AT 74° F.; 72 PERCENT SOIL MOISTURE							
Sept. 21	3,100	2,120	2,120	2,080	0.684	0.684	0.671
Sept. 25	2,950	1,250	1,030	1,730	.424	.349	.586
Sept. 27	3,300	1,290	1,090	1,670	.391	.330	.506
Sept. 29	2,800	1,450	1,000	1,440	.518	.357	.514
Oct. 2	5,550	2,300	1,990	2,850	.414	.359	.514
Oct. 5	6,625	2,650	2,075	3,625	.400	.313	.547
Oct. 8	7,400	2,450	2,090	3,985	.331	.282	.539
Oct. 12	12,550	4,900	4,060	7,350	.390	.334	.586
Oct. 15	16,225	6,650	5,650	10,300	.410	.348	.635
Oct. 17	8,275	3,975	3,400	5,950	.480	.411	.818
Oct. 20	11,400	5,750	4,900	8,825	.504	.430	.774
Oct. 22	7,900	4,350	3,525	6,525	.551	.446	.826
Oct. 24	10,400	5,750	4,600	8,350	.553	.442	.803
Oct. 26	5,425	3,375	2,950	5,200	.622	.544	.959
Oct. 29	9,525	6,000	5,125	8,575	.630	.538	.900
Oct. 31	7,225	5,000	4,400	6,825	.692	.609	.945
Nov. 2	9,625	7,850	7,350	9,850	.816	.764	1.023
Nov. 4	7,425	6,300	6,075	7,625	.848	.818	1.027
Nov. 6	5,100	4,500	4,450	5,400	.882	.873	1.059
Nov. 8	7,150	6,700	6,750	7,900	.937	.944	1.105
Nov. 10	7,100	6,100	6,300	7,100	.859	.887	1.000
Nov. 12	5,250	4,850	4,750	5,450	.924	.905	1.038
Nov. 14	7,100	6,700	6,850	7,650	.944	.965	1.077
Nov. 16	5,150	4,550	4,800	5,200	.883	.932	1.010
Nov. 19	9,950	10,250	10,550	11,050	1.030	1.060	1.111
Nov. 21	6,500	7,450	7,800	7,900	1.146	1.200	1.215
Total	191,000	124,510	115,680	160,405			
UNIT 1, AT 74° F.; 86 PERCENT SOIL MOISTURE							
Sept. 21	4,100	2,730	2,840	3,110	0.666	0.693	0.759
Sept. 25	3,830	1,920	2,090	2,480	.501	.546	.648
Sept. 27	4,290	2,060	2,220	2,830	.480	.517	.660
Sept. 29	3,590	1,420	1,780	2,350	.396	.496	.655
Oct. 2	6,970	3,120	3,790	4,750	.448	.544	.681
Oct. 5	7,750	3,800	4,525	5,650	.490	.584	.729
Oct. 8	7,925	4,400	4,925	6,150	.555	.621	.776
Oct. 12	13,400	7,800	8,800	11,000	.582	.657	.821
Oct. 15	15,975	10,950	12,125	14,350	.685	.759	.898
Oct. 17	7,795	6,400	6,780	7,660	.821	.870	.983
Oct. 20	11,550	10,000	10,450	11,275	.866	.905	.976
Oct. 22	7,950	7,375	7,775	8,325	.928	.978	1.047
Oct. 24	11,400	10,550	10,700	11,500	.925	.939	1.009
Oct. 26	5,775	5,650	5,750	6,225	.978	.996	1.078
Oct. 29	10,975	10,350	10,400	11,300	.943	.948	1.030
Oct. 31	8,425	8,500	8,350	9,100	1.009	.991	1.080

TABLE 8.—*Comparison of the daily transpiration of unfertilized and fertilized tomato plants grown in nine different soil environments, 1934*—Continued

UNIT 1, AT 74° F.; 86 PERCENT SOIL MOISTURE—Continued

Period ended	Water transpired from—				Transpiration ratio of—		
	Unfertilized check	Plants receiving fertilizer—			Plants receiving fertilizer—		
		12-0-12	12-6-12	6-12-6	12-0-12	12-6-12	6-12-6
	Ml.	*Ml.*	*Ml.*	*Ml.*			
Nov. 2	11,300	12,475	12,075	13,250	1.104	1.069	1.173
Nov. 4	8,425	9,950	9,700	10,325	1.181	1.151	1.226
Nov. 6	5,600	7,350	6,850	7,100	1.312	1.223	1.268
Nov. 8	8,850	10,750	9,750	9,950	1.215	1.102	1.124
Nov. 10	7,800	9,800	8,650	8,800	1.256	1.109	1.128
Nov. 12	6,250	7,850	7,100	7,550	1.256	1.136	1.208
Nov. 14	8,150	10,500	9,150	10,000	1.288	1.123	1.229
Nov. 16	5,150	8,100	6,450	6,900	1.573	1.252	1.340
Nov. 19	9,650	16,150	13,750	13,850	1.674	1.425	1.435
Nov. 21	6,800	11,500	9,800	9,750	1.691	1.441	1.434
Total	209,675	201,450	196,575	215,530			

UNIT 2, AT 70° F.; 59 PERCENT SOIL MOISTURE

Sept. 21	3,200	1,700	1,900	2,100	0.531	0.594	0.656
Sept. 25	1,910	510	620	780	.267	.325	.408
Sept. 27	2,340	1,090	1,170	1,260	.466	.500	.538
Sept. 29	1,630	750	830	950	.460	.509	.583
Oct. 2	4,040	1,540	1,630	1,950	.381	.403	.483
Oct. 5	4,315	1,475	1,545	1,940	.342	.358	.450
Oct. 8	3,780	1,370	1,450	1,760	.362	.384	.466
Oct. 12	7,590	2,325	2,380	3,265	.306	.314	.430
Oct. 15	8,300	2,950	2,820	3,825	.355	.340	.461
Oct. 19	7,700	2,800	2,850	3,800	.364	.370	.494
Oct. 21	5,075	1,875	1,950	2,550	.369	.384	.502
Oct. 23	4,525	1,650	1,925	2,400	.365	.425	.530
Oct. 25	5,250	1,975	2,250	2,900	.376	.429	.552
Oct. 29	6,375	2,625	2,875	3,775	.412	.451	.592
Nov. 1	6,375	3,200	3,425	4,200	.502	.537	.659
Nov. 3	4,950	2,900	2,950	3,650	.586	.596	.737
Nov. 5	4,300	2,675	2,625	3,275	.622	.610	.762
Nov. 7	4,650	3,050	2,900	3,700	.656	.624	.796
Nov. 9	4,150	2,500	2,350	3,000	.602	.566	.723
Nov. 12	6,050	3,675	3,475	4,675	.607	.574	.773
Nov. 14	4,100	2,550	2,350	3,250	.622	.573	.793
Nov. 16	3,050	2,150	1,900	2,450	.705	.623	.803
Nov. 19	7,400	5,600	4,600	6,400	.757	.622	.865
Nov. 22	5,300	3,800	3,300	4,450	.717	.623	.840
Total	116,355	56,735	56,070	72,305			

UNIT 2, AT 70° F.; 72 PERCENT SOIL MOISTURE

Sept. 21	2,790	2,070	1,840	2,170	0.742	0.659	0.778
Sept. 25	2,510	1,240	1,180	1,740	.494	.470	.693
Sept. 27	3,040	1,450	1,180	1,890	.477	.388	.622
Sept. 29	2,190	1,040	830	1,200	.475	.397	.548
Oct. 2	4,860	2,370	1,780	2,910	.488	.366	.599
Oct. 5	5,450	2,430	2,105	3,460	.456	.386	.635
Oct. 8	5,600	2,180	1,910	3,160	.389	.341	.564
Oct. 12	11,225	4,825	4,475	6,975	.430	.399	.621
Oct. 15	12,725	5,750	5,175	8,300	.452	.407	.652
Oct. 19	11,300	5,700	5,250	8,400	.504	.465	.743
Oct. 21	7,575	4,300	4,050	5,700	.568	.535	.752
Oct. 23	6,625	4,125	3,975	5,500	.623	.600	.830
Oct. 25	7,825	5,025	4,550	6,625	.642	.581	.847
Oct. 29	9,025	6,550	5,875	8,050	.726	.651	.892
Nov. 1	9,675	7,575	6,725	9,250	.783	.695	.956
Nov. 3	7,700	6,300	6,050	8,050	.818	.786	1.045
Nov. 5	6,725	5,800	5,725	7,125	.862	.851	1.059
Nov. 7	6,950	6,550	6,450	7,700	.942	.928	1.108
Nov. 9	5,350	5,700	5,650	6,300	1.065	1.056	1.178
Nov. 12	7,550	7,875	7,750	8,200	1.043	1.026	1.086
Nov. 14	4,800	5,350	5,250	5,450	1.115	1.094	1.135
Nov. 16	4,050	4,050	4,125	4,425	1.000	1.019	1.093
Nov. 19	8,850	10,400	10,650	11,150	1.175	1.203	1.260
Nov. 22	6,825	7,200	7,400	7,225	1.055	1.084	1.059
Total	161,215	115,855	109,950	140,955			

TABLE 8.—*Comparison of the daily transpiration of unfertilized and fertilized tomato plants grown in nine different soil environments, 1934*—Continued

UNIT 2, AT 70° F.; 86 PERCENT SOIL MOISTURE

Period ended	Water transpired from—				Transpiration ratio of—		
	Unfertilized check	Plants receiving fertilizer—			Plants receiving fertilizer—		
		12-0-12	12-6-12	6-12-6	12-0-12	12-6-12	6-12-6
	Ml.	*Ml.*	*Ml.*	*Ml.*			
Sept. 21	4,030	2,260	2,620	3,330	0.561	0.650	0.826
Sept. 25	3,760	1,810	2,070	2,690	.481	.551	.715
Sept. 27	4,260	2,180	2,350	3,090	.512	.552	.725
Sept. 29	2,860	1,300	1,450	2,150	.455	.507	.752
Oct. 2	6,550	3,260	3,370	4,940	.498	.515	.754
Oct. 5	7,175	3,650	3,800	5,925	.509	.530	.826
Oct. 8	6,200	3,550	3,400	5,350	.573	.548	.863
Oct. 12	13,250	7,975	7,675	11,425	.602	.579	.862
Oct. 15	13,125	9,500	9,000	12,600	.724	.686	.960
Oct. 19	11,500	9,500	9,050	11,550	.826	.787	1.004
Oct. 21	7,025	6,875	6,450	7,850	.979	.918	1.117
Oct. 23	6,825	6,475	5,900	7,125	.949	.864	1.044
Oct. 25	7,875	7,825	7,000	8,425	.994	.889	1.070
Oct. 29	9,800	9,675	8,775	10,475	.987	.895	1.069
Nov. 1	9,550	11,025	9,925	11,275	1.154	1.039	1.181
Nov. 3	7,900	9,350	8,550	9,650	1.184	1.082	1.222
Nov. 5	6,400	8,475	7,675	8,225	1.324	1.199	1.285
Nov. 7	7,000	9,100	8,500	9,050	1.300	1.214	1.293
Nov. 9	6,200	8,050	7,250	7,000	1.298	1.169	1.129
Nov. 12	7,950	10,600	9,700	9,575	1.333	1.220	1.204
Nov. 14	4,900	7,150	6,650	6,400	1.454	1.357	1.306
Nov. 16	3,975	6,050	5,700	5,225	1.522	1.434	1.314
Nov. 19	8,600	15,200	13,850	11,950	1.767	1.610	1.390
Nov. 22	7,000	10,900	9,850	9,200	1.557	1.407	1.314
Total	173,710	171,735	160,560	184,475			

UNIT 3, AT 66° F.; 59 PERCENT SOIL MOISTURE

Sept. 21	3,320	1,920	2,200	2,400	0.578	0.663	0.723
Sept. 25	2,000	500	550	790	.250	.275	.395
Sept. 29	4,430	2,180	1,840	2,745	.492	.415	.620
Oct. 2	4,260	1,730	1,800	2,420	.406	.423	.568
Oct. 5	4,500	1,365	1,590	2,310	.303	.353	.513
Oct. 8	4,240	1,360	1,210	1,920	.321	.285	.453
Oct. 12	8,200	2,610	2,555	4,350	.318	.312	.530
Oct. 15	8,050	2,820	2,660	4,550	.350	.330	.565
Oct. 19	7,550	2,725	2,500	4,475	.361	.331	.593
Oct. 22	7,550	2,750	2,500	4,800	.364	.331	.636
Oct. 24	5,900	2,200	1,950	4,100	.373	.331	.695
Oct. 26	3,550	1,350	1,250	2,350	.380	.352	.662
Oct. 30	7,100	2,950	2,650	5,000	.415	.373	.704
Nov. 1	4,200	2,000	1,750	3,200	.476	.417	.762
Nov. 3	5,550	2,800	2,600	4,200	.505	.468	.757
Nov. 5	4,150	2,450	2,300	3,550	.590	.554	.855
Nov. 7	5,300	3,250	3,000	4,700	.613	.566	.887
Nov. 9	3,300	2,300	2,200	3,275	.697	.667	.992
Nov. 11	4,250	3,075	3,000	4,275	.724	.706	1.006
Nov. 13	2,450	1,950	1,875	2,575	.796	.765	1.051
Nov. 15	2,900	2,600	2,425	3,225	.897	.836	1.112
Nov. 17	4,950	4,400	4,250	5,750	.889	.859	1.162
Nov. 20	4,450	4,250	4,350	5,550	.955	.978	1.247
Nov. 22	1,600	1,950	2,000	2,150	1.219	1.250	1.344
Total	113,750	57,485	55,005	84,660			

UNIT 3, AT 66° F.; 72 PERCENT SOIL MOISTURE

Sept. 21	3,040	2,210	2,250	2,760	0.727	0.740	0.908
Sept. 25	2,520	1,360	1,250	1,730	.540	.496	.687
Sept. 29	5,545	2,900	2,800	3,965	.523	.505	.715
Oct. 2	4,960	2,780	2,325	3,410	.560	.469	.687
Oct. 5	5,450	2,625	2,375	3,700	.482	.436	.679
Oct. 8	5,300	2,380	2,250	3,500	.449	.425	.660
Oct. 12	11,300	5,325	4,850	7,450	.471	.429	.659
Oct. 15	10,800	5,600	5,300	8,000	.519	.491	.741
Oct. 19	9,375	5,625	5,475	7,750	.600	.584	.827
Oct. 22	9,750	6,050	6,000	8,300	.627	.615	.851

TABLE 8.—*Comparison of the daily transpiration of unfertilized and fertilized tomato plants grown in nine different soil environments, 1934*—Continued

UNIT 3, AT 66° F.; 72 PERCENT SOIL MOISTURE

Period ended	Water transpired from—				Transpiration ratio of—		
	Unfertilized check	Plants receiving fertilizer—			Plants receiving fertilizer—		
		12-0-12	12-6-12	6-12-6	12-0-12	12-6-12	6-12-6
	Ml.	*Ml.*	*Ml.*	*Ml.*			
Oct. 24	7,850	5,300	5,150	6,950	0.675	0.656	0.885
Oct. 26	4,475	3,125	3,075	3,975	.698	.687	.888
Oct. 30	9,500	6,700	6,950	8,600	.705	.732	.905
Nov. 1	5,000	4,100	4,200	4,950	.820	.840	.990
Nov. 3	6,750	5,500	5,950	7,000	.815	.881	1.037
Nov. 5	5,000	4,750	4,950	5,600	.950	.990	1.120
Nov. 7	6,400	6,150	6,450	7,400	.961	1.008	1.156
Nov. 9	4,325	4,375	4,700	5,125	1.012	1.087	1.185
Nov. 11	5,325	5,350	5,725	6,150	1.005	1.075	1.155
Nov. 13	3,100	3,175	3,275	3,800	1.024	1.056	1.226
Nov. 15	3,650	3,925	4,075	4,800	1.075	1.116	1.315
Nov. 17	5,800	7,050	7,500	7,800	1.216	1.293	1.345
Nov. 20	5,500	7,150	7,800	7,600	1.300	1.418	1.382
Nov. 22	2,600	3,000	3,200	3,050	1.154	1.231	1.193
Total	143,315	106,505	107,875	133,365			

UNIT 3, AT 66° F.; 86 PERCENT SOIL MOISTURE

Sept. 21	5,320	3,260	3,200	4,140	0.613	0.602	0.778
Sept. 25	4,020	2,030	1,760	2,700	.505	.438	.672
Sept. 29	9,330	4,560	4,035	6,255	.489	.432	.670
Oct. 2	7,690	3,890	3,140	5,430	.506	.408	.706
Oct. 5	7,750	4,000	3,550	5,925	.516	.458	.765
Oct. 8	7,400	3,900	3,300	5,600	.527	.446	.757
Oct. 12	15,175	8,850	7,225	12,025	.583	.476	.792
Oct. 15	13,300	9,200	7,400	11,800	.692	.556	.887
Oct. 19	11,025	8,850	7,325	10,875	.803	.664	.986
Oct. 22	10,000	9,350	7,550	10,900	.935	.755	1.090
Oct. 24	8,250	8,000	6,450	9,200	.970	.782	1.115
Oct. 26	4,800	4,750	4,075	5,775	.990	.849	1.203
Oct. 30	10,000	10,500	8,900	12,450	1.050	.890	1.245
Nov. 1	5,350	5,900	5,100	6,800	1.103	.953	1.271
Nov. 3	7,450	8,150	7,300	9,450	1.094	.980	1.268
Nov. 5	5,200	6,500	5,750	6,950	1.250	1.106	1.337
Nov. 7	7,100	8,300	7,750	9,550	1.169	1.092	1.345
Nov. 9	4,725	5,850	5,425	6,375	1.238	1.148	1.349
Nov. 11	5,825	7,375	6,850	8,125	1.266	1.176	1.395
Nov. 13	3,275	4,225	3,975	4,825	1.290	1.214	1.473
Nov. 15	3,975	5,275	4,975	5,525	1.327	1.252	1.390
Nov. 17	6,400	9,100	8,900	9,600	1.422	1.391	1.500
Nov. 20	6,200	9,100	8,800	9,300	1.468	1.419	1.500
Nov. 22	2,750	4,050	3,650	3,950	1.473	1.327	1.436
Total	172,310	151,965	136,385	183,525			

It is obvious that the daily transpiration of all plants increased with increase in size, and later declined during the cloudy months of fall and winter; however, it is also apparent that certain of the check plants had a greater decline in their daily transpiration than did the corresponding fertilized plants. There was some difference in the time when the plants were topped, but this difference was due primarily to the effect of soil moisture and temperature and not to fertilizer treatment. The majority of the plants were topped during the last two weeks of October before any considerable decline in transpiration occurred. Topping the plants after the appearance of the sixth flower cluster produced plants of nearly the same size and weight. The relative plant sizes are indicated by the data given in table 4 on the dry weight of the plants.

A detailed interpretation of the data presented in table 8 can best be made by diagrams or graphs. Figure 1 illustrates the gradual change in the rate of transpiration of the check plants, associated apparently with the exhaustion of nutrients in the soil, as compared with the 12–6–12 fertilized plant culture. This diagram is based on

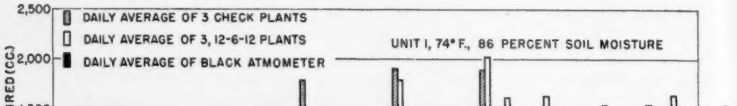

FIGURE 1.—Daily transpiration of three fertilized (12–6–12) and of three unfertilized tomato plants averaged during 2- to 4-day periods for the last 64 days of growth, with corrected black-atmometer index to indicate the relative evaporation intensity during the same periods. Plants grown in greenhouse unit 1, at 74° F. and 86 percent soil moisture.

the average daily amounts of water transpired per plant over 2- to 4-day periods during the 64 days of growth at 74° F. Marked changes in the rate of transpiration were indicated, although the soil-moisture content was maintained at a fairly constant level of approximately 86 percent of water-retaining capacity. The corrected atmometer index is shown for the period in order to give some idea of

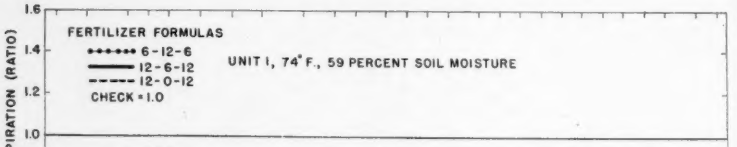

FIGURE 2.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 1, 74° F., 59 percent soil moisture.

the evaporation intensities. The amount of water transpired per day from the check plants exceeded that from the 12–6–12 fertilized plants during the first 43 days. After the forty-third day, October 31, there was a sufficient decrease in the daily transpiration of the check plants to cause it to fall below the level of the 12–6–12 plant culture

while the transpiration of the latter continued with comparatively slight change.

The data given in table 8 relating to the ratios of the transpiration of the fertilized to that of the respective unfertilized check cultures of tomatoes are presented graphically in figures 2 to 10.

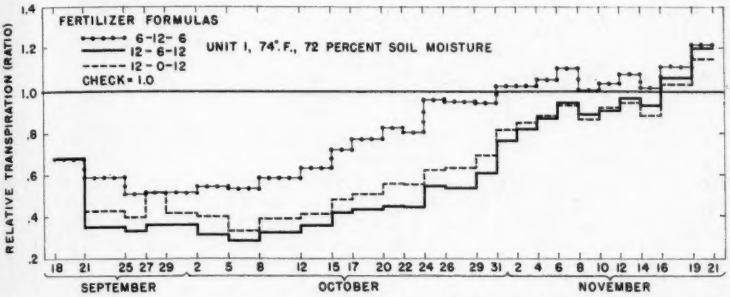

FIGURE 3.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 1, 74° F., 72 percent soil moisture.

With the check plants equaling 1.0 as a basis for comparison, figures 2 to 10 show the rather marked changes in the transpiration ratios of the fertilized to the respective unfertilized check plants. It is important to observe that whereas the check plants transpired much more water than did the fertilized plants of about the same

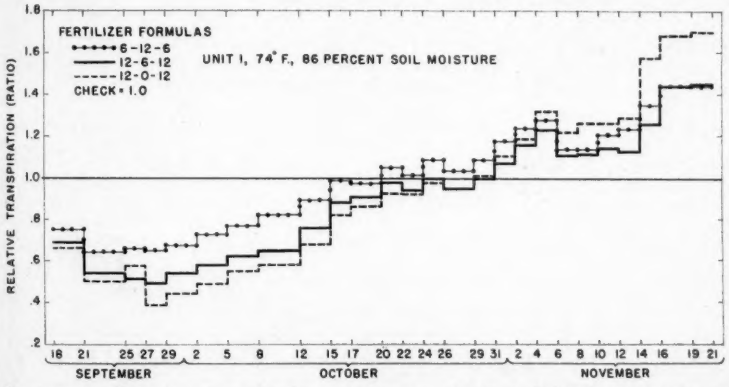

FIGURE 4.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 1, 74° F., 86 percent soil moisture.

size, as indicated by early and total amounts, their transpiration fell off gradually in many cases, while the fertilized plants (still about the same size as the checks) did not show an equal decline in the amount of transpiration; therefore, in such cases the checks gradually dropped below the fertilized plants. These trends are definite and are reflected in the increasing values of the ratios based on the check

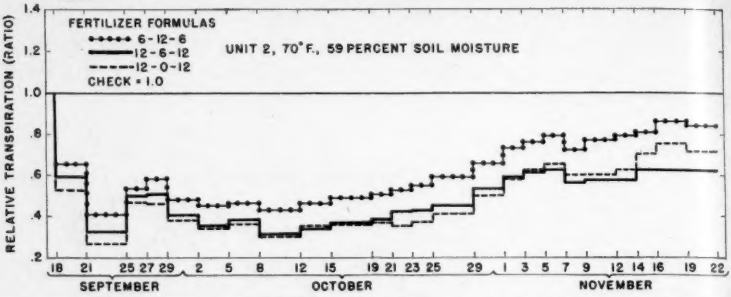

FIGURE 5.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 2, 70° F., 59 percent soil moisture.

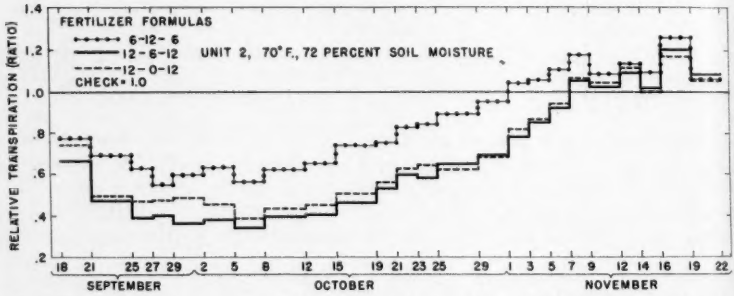

FIGURE 6.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 2, 70° F., 72 percent soil moisture.

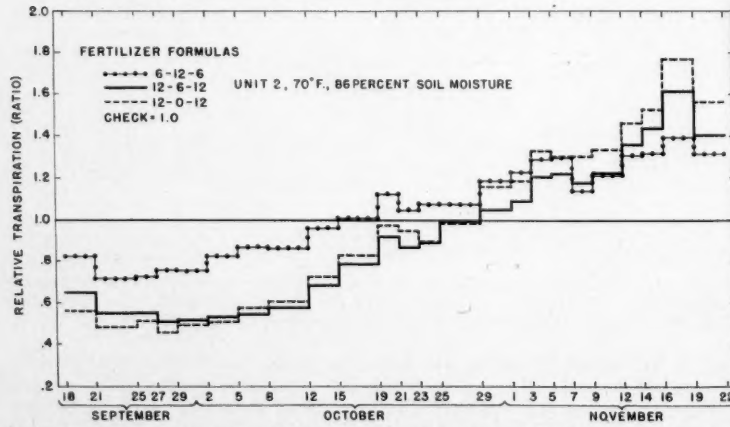

FIGURE 7.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 2, 70° F., 86 percent soil moisture.

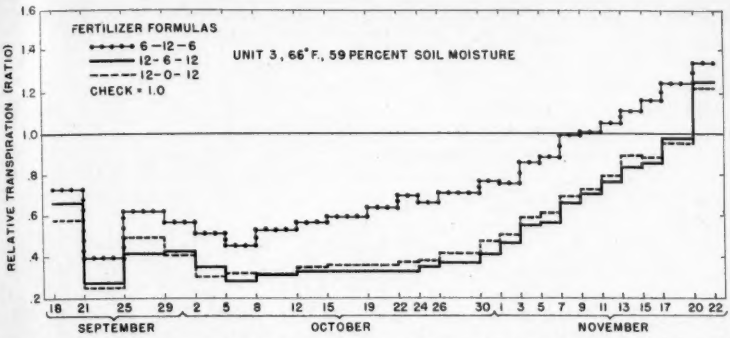

FIGURE 8.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 3, 66° F., 59 percent soil moisture.

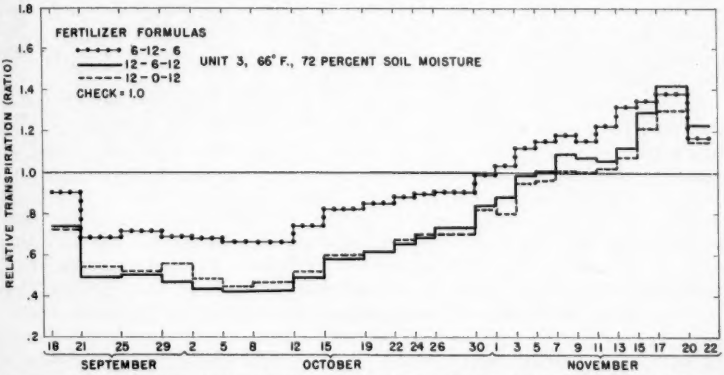

FIGURE 9.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 3, 66° F., 72 percent soil moisture.

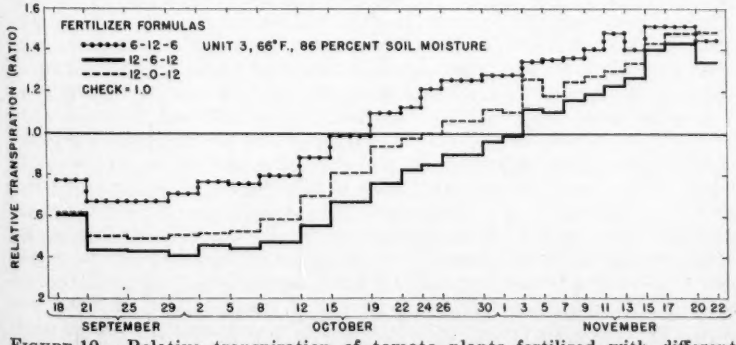

FIGURE 10.—Relative transpiration of tomato plants fertilized with different amounts of nutrients, in comparison with the unfertilized check taken as unity. Based on data from table 8, unit 3, 66° F., 86 percent soil moisture.

plants as unity. Once the ratio lines cross the unity base line they do not recross; and there is little or no subsequent downward trend.

This change in ratio of water transpired was rather marked even with low soil moisture, 59 percent (figs. 2, 5, and 8); but at this moisture level the ratio of transpiration of the fertilized to the check plants exceeded 1.0 only when the plants were grown at 66° F. The marked changes in the transpiration of the check plants are interesting, since the dry weights of the check plants exceeded those of the fertilized ones at all temperatures when grown at a low soil-moisture level (table 4).

The effect of 72 percent soil moisture was to hasten the relative transpiration change, as indicated by figures 3, 6, and 9. At this soil-moisture level there was a more rapid change in the ratios of transpiration and also there were larger differences between the transpiration ratios of the several treatments than was the case at a 59-percent soil-moisture level. There was also an increase in dry weights of the plants in these moister cultures, as is indicated by data in table 4.

The transpiration change occurred at an even earlier date when the plants were grown with 86 percent soil moisture. There was also a more rapid growth of the plants, which would tend to exhaust the soil nutrients earlier (figs. 4, 7, and 10).

It is obvious from the data given that many factors affect growth response and transpiration. Attention should be called to the deleterious effects of low soil moisture (59 percent of water-retaining capacity), at which level growth was retarded rather markedly by the applied fertilizer—evidently toxic under these cultural conditions because of the high osmotic strength of the soil solution. This fact is indicated by the larger dry weight of the check plants and the greater use of water per unit of dry weight. It also appears that growth of the check plants was retarded to such an extent that the soil nutrients were not totally exhausted; consequently, there was a relatively small change in the transpiration of the check plants at this low soil-moisture level. However, at the low temperature (66° F.) the transpiration of the check plants exceeded that of the fertilized plants until after the fifty-third and sixty-fourth day, when the declining transpiration of the check plants dropped below that of the fertilized plants (fig. 8). The close similarity under all conditions of the daily transpiration of the two fertilized cultures 12–0–12 and 12–6–12 is striking, but this phenomenon is difficult to explain adequately (*20*). This relation of the transpiration of these cultures is apparent in figures 2 to 10, inclusive, with the curves for the 12–0–12 cultures closely following those for the 12–6–12 cultures.

The growth rate of the plants at 72 percent soil moisture exceeded that of the plants grown at 59 percent soil moisture at all temperatures, and as a result soil nutrients were exhausted earlier and more rapidly. The faster growth of these plants at 72 percent soil moisture was associated with a more rapid and earlier decline in the transpiration of the check plants when compared with the fertilized plants than was the case at the 59-percent soil-moisture level (figs. 3, 6, and 9). At the high temperature (74° F.), the rate of transpiration of the check plants exceeded that of the 12–0–12 and 12–6–12 fertilized plants until November 19, and that of the 6–12–6 plants until November 2, after

which dates the transpiration of the fertilized cultures exceeded that of the check. At 70° the rate of transpiration of the check plants exceeded that of the 12–0–12 and 12–6–12 fertilized cultures until November 9, and that of the 6–12–6 until November 3, after which dates the fertilized plants transpired larger amounts of water over equal periods. These facts appear to indicate a definite measurable decline in the rate of transpiration of the check plants after nutrient depletion in the soil. The rate of transpiration of the check plants grown at 66° exceeded that of the 12–0–12 plants until November 9, that of the 12–6–12 plants until November 7, and that of the 6–12–6 plants until November 3, after which dates the rate of transpiration of the fertilized plants exceeded that of the check plants.

The largest increase in plant growth and fruit yield occurred with plants grown at 86 percent soil moisture in all three temperature units. At 74° F. the rate of transpiration of the check plants exceeded that of the 12–0–12 fertilized plants until October 31, that of the 12–6–12 plants until November 2, and that of the 6–12–6 plants until October 22 (figs. 4, 7, and 10). At 70° the rate of transpiration of the check plants exceeded that of the 12–0–12 and 12–6–12 fertilized cultures until November 1, and that of the 6–12–6 culture until October 19, after which dates there was a definite measurable decline in the rate of transpiration of the check plants (fig. 7). At 66° the rate of transpiration of the check plants exceeded that of the 12–0–12 fertilized plants until October 30, that of the 12–6–12 plants until November 5, and that of the 6–12–6 plants until October 22 (fig. 10). These facts are a further indication of a definite measurable decline in the transpiration of unfertilized plants that occurred concurrently with the exhaustion of soil nutrients.

DISCUSSION

The extensive data presented in both table and graph emphasize the effects of soil moisture, soil nutrients, and temperature on the general growth habits of the tomato, on the total water expenditure, on the daily transpiration, on periodic changes in the daily amount of transpiration, and on the starch content of the plants. It is obvious that additional data would be helpful in drawing conclusions. Measurements of the leaf area of the plants in the respective cultures would have been valuable but were impossible to obtain with so large a group of plants. The only available data showing comparative size of unfertilized and fertilized plants are those in table 4 showing the dry weights of the vegetative part of the plants. Dry and green weights of the leaf part of the plants are available, but these would not be adequate for determining the rate of transpiration per unit area, since it is assumed that some transpiration takes place through the stem. Furthermore, the dry weight of the leaf part of the plant shows a straight-line relationship to the total vegetative dry weight of the plant, hence the two are equally serviceable as criteria of size. The data given in tables 2 to 4 show striking differences in magnitude because of fertilizer, soil moisture, and temperature differences. One important and notable exception is that no significant differences due to fertilizer are indicated by the mean square of the dry weight of the plants, but interaction involving fertilizer × moisture is highly significant (table 4). However, fertilizer had a highly significant effect

(with odds greater than 99:1) on the water requirement (table 2) and on the total water transpired (table 3) during the experimental period. These data in tables 2 to 4 and the statistical analysis included with each table are very good examples of data that may lead one astray in attempting an explanation of a series of events when only the end result is observed. In tables 2 and 3, in the analysis of variance, highly significant differences are indicated which to the casual observer might lead to the general conclusion that the check plants had the highest rate of transpiration per plant throughout the entire period of the experiment. Data presented in table 8 and the graphic presentation of these data in figures 2 to 10 show very strikingly why such an interpretation would be incorrect. It is quite evident that a rather marked decline in the transpiration of the check plants occurred concurrently with the exhaustion of the soil nutrients and nitrogen (*10*).

Data on water requirement for entire growth periods have been used as a basis for the following concept: "When the supply of nutrients in the soil approaches exhaustion, the rate of growth of the plant is greatly reduced, but no corresponding change occurs in the transpiration rate. This fact is evidence that transpiration is not a measure of growth" (*15, p. 500*). Data that give only the final water requirement (or water expenditure per gram of gain in plant weight) are not valid for supporting the concept just quoted. Data based on the total water transpired cannot possibly reveal what happened to the rate of transpiration of the plants before or after the soil nutrients were exhausted or during any other limited period; they indicate merely that the check plants averaged a relatively higher rate of transpiration over the entire test period.

The large accumulation of starch in the stem and leaf parts (tables 6 and 7) of the unfertilized check plants was highly significant and differed from that of the fertilized group of tomato plants with odds greater than 99:1. These data appear to indicate that a definite change in the metabolism of the check plants has resulted because of the apparent exhaustion of soil nutrients. These data also suggest that a process of dehydration was initiated, with a large part of the carbohydrate content of the check plants becoming inactive, a further indication of retarded metabolism (*10*). The decline in the daily transpiration of the check plants was concurrent with this apparent retarded metabolism and growth, and is illustrated by the data presented in table 8 and in figures 2 to 10. Lloyd (*13*) and Iljin (*11*) called attention to the fact that high starch content of the leaves was usually associated with stomatal closing, and these authors suggested a possible relation to retarded transpiration.

SUMMARY

In this paper extensive data are submitted that show differences in the daily amount of transpiration of tomato plants (*Lycopersicon esculentum* Mill.) when grown in the greenhouse in soil with 4 nutrient treatments under 9 sets of environmental conditions involving 3 variations in soil moisture and 3 in air temperature, giving altogether 36 points of observation for study. Evaporation capacities of the air under the three conditions of temperature were measured.

With increasing amounts of soil moisture and decreasing temperature, there was a corresponding increase in the rate of plant growth that was directly correlated with the early exhaustion of soil nutrients in the unfertilized cultures—a condition which was further reflected by a definite, measurable decline in the transpiration of the unfertilized plants. This decline in transpiration was relatively large at high soil-moisture levels.

Data treated statistically by the method of analysis of variance indicate the highly significant effects of soil moisture, soil nutrients, and temperature on total water transpired, on the water requirement, on the fruit yield, and on the starch content of stem and leaf parts of tomato plants. Temperature and soil moisture, but not soil nutrients, had a highly significant effect on the final dry weight of the plants, all of which were topped uniformly after the appearance of the sixth flower cluster and pruned for removal of all axillary growth.

LITERATURE CITED

(1) Alexandroff, B.
1924. Sur l'intensité de la transpiration de quelques plantes herbacées. Tiflis Bot. Gard., Appl. Sect. Sci. Papers 4: 1–28. [In Russian. Summary in French, p. 28.]

(2) Briggs, Lyman J., and Shantz, H. L.
1913. The water requirement of plants. I. Investigations in the great plains in 1910 and 1911. U. S. Dept. Agr., Bur. Plant Indus. Bul. 284, 49 pp., illus.

(3) ——— and Shantz, H. L.
1913. The water requirement of plants. II. A review of the literature. U. S. Dept. of Agr., Bur. Plant Indus. Bul. 285, 96 pp., illus.

(4) ——— and Shantz, H. L.
1914. Relative water requirement of plants. Jour. Agr. Res. 3: 1–63, illus.

(5) Burgerstein, Alfred.
1904. Die transpiration der pflanzen. Eine physiologische monographie. 283 pp., illus. Jena.

(6) ———
1920. Die transpiration der pflanzen. Zweiter teil. 264 pp., illus. Jena.

(7) Clapp, Grace Lucretia.
1908. A quantitative study of transpiration. Bot. Gaz. 45: 254–267, illus.

(8) Curtis, Otis F.
1926. What is the significance of transpiration? Science (n. s.) 63: 267–271.

(9) Dixon, Henry H.
1914. Transpiration and the ascent of sap in plants. 216 pp., illus. New York.

(10) Foster, Arthur C., and Tatman, Everett C.
1938. Influence of certain environmental conditions on congestion of starch in tomato plant stems. Jour. Agri. Res. 56: 869–882, illus.

(11) Iljin, W. S.
1914. Die regulierung der spaltöffnungen im zusammenhang mit der veränderung des osmotischen druckes. Bot. Centbl. Beihefte, Abt. 1, Anat., Histol., Morph., u. Physiol. der Pflanz. 32: 15–35, illus.

(12) Kiesselbach, T. A.
1916. Transpiration as a factor in crop production. Nebr. Agr. Expt. Sta. Res. Bul. 6, 214 pp., illus.

(13) Lloyd, Francis Ernest.
1908. The physiology of stomata. Carnegie Inst. Wash., Pub. 82, 142 pp., illus.

(14) MAXIMOV, N. A.
1929. THE PLANT IN RELATION TO WATER. A STUDY OF THE PHYSIOLOGICAL BASIS OF DROUGHT RESISTANCE. 451 pp., illus. London. [English trans. by R. H. Yapp.]
(15) MILLER, EDWIN C.
1938. PLANT PHYSIOLOGY, WITH REFERENCE TO THE GREEN PLANT. Ed. 2, 1201 pp., illus. New York and London.
(16) SNEDECOR, GEORGE W.
1934. CALCULATION AND INTERPRETATION OF ANALYSIS OF VARIANCE AND COVARIANCE. 96 pp. Ames, Iowa. (Iowa State Col., Div. Indus. Sci. Monog. 1.)
(17) ———
1937. STATISTICAL METHODS APPLIED TO EXPERIMENTS IN AGRICULTURE AND BIOLOGY. 341 pp., illus. Ames, Iowa.
(18) SNOW, ALBERT G., Jr.
1936. TRANSPIRATION AS MODIFIED BY POTASSIUM. Plant Physiol. 11: 583–594, illus.
(19) SRESNEVSKI, B. J.
1905. [ON EVAPORATION FROM THE SURFACE OF THE HUMAN BODY AND FROM PLANTS.] 2d Climatol. and Hydrol. Cong., St. Petersburg, Proc. 1: 311–333. [In Russian. Cited by Maximov (*14, p. 423*).]
(20) UDOLSKAJA, N.
1934. CONTRIBUTION TO THE STUDY OF THE ELEMENTS OF MINERAL NUTRITION AND OF FACTORS CHANGING THE DROUGHT RESISTANCE OF PLANTS. Acad. des. Sci. U. R. S. S. Compt. Rend. (Dok.) 2: 45–46. [In Russian. English translation, pp. 47–48. Abstract in Chem. Abs. 28: 5100. 1934.]

EFFECT OF CERTAIN FUNGICIDES AND ENVIRONMENTAL FACTORS ON THE RATE OF TRANSPIRATION OF TOMATO PLANTS[1]

By ARTHUR C. FOSTER, *senior pathologist*, and EVERETT C. TATMAN, *assistant scientific aide, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

The effect on rate of transpiration of the application of certain fungicides to the foliage of plants has attracted considerable attention during the past 25 years. Recently, however, this interest has become more intense because of the effect of a number of these fungicides, especially those containing zinc sulfate or copper phosphate, on the growth and metabolic responses of the plant. In many of the experiments reported, the plants used were young, the foliage was tender, and the apparent increase in rate of transpiration was due to injury by the fungicide and subsequent desiccation and cuticular loss, as suggested by Horsfall and Harrison (*17*).[2] At the present time it appears that when certain fungicides are applied to young, tender plants there is a definite measurable increase in the rate of transpiration, but when applied to old, mature plants the rate of transpiration changes little. Very few data have appeared in the literature that show the effects of these fungicides on the rate of transpiration of large, bearing plants, when grown under widely different environmental conditions.

Since fungicides are also applied to large, bearing plants when grown under field conditions in commercial practice, the rate of transpiration and the metabolic responses of the plants under these conditions are of considerable importance. Therefore, any additional quantitative data secured under conditions approaching those of normal crop plant growth, where the effects of several environmental factors affecting the rate of transpiration are measured concurrently with the effects of certain fungicides, would appear to be desirable in evaluating and interpreting many factors involved in this problem.

In this paper, data are presented showing the independent effects and interactions of fungicides and environmental factors on the rate of transpiration of maturing tomato plants (*Lycopersicon esculentum* Mill.)

REVIEW OF LITERATURE

The literature relating to the effect of fungicides on the rate of transpiration of plants is extensive and varied. The following workers have all reported an increase in the rate of transpiration due to the application of fungicides either on detached leaves or, in many experiments, on young potted plants: Bain (*1*), Bonde (*3*, *4*), Butler (*5*), Duggar and Cooley (*9*, *10*), Duggar and Bonns (*8*),

[1] Received for publication August 30, 1940.
[2] Italic numbers in parentheses refer to Literature Cited, p. 733.

Dutton and Wells (*11*), Frank and Krüger (*15*, *16*), Krausche and Gilbert (*18*), Martin (*21*), Martin and Clark (*22*), Runnels and Wilson (*25*), Shive and Martin (*27*), Wilson and Runnels (*30*, *31*, *32*), and Zucker (*33*).[3] A number of other investigators have failed to find very marked effects of fungicides on the rate of transpiration when, in most instances, normal or field types of plants were used. Among these are Bayer (*2*),[4] Childers (*6*), Clinton (*7*), Ewert (*12*), Horsfall and Harrison (*17*), Lutman (*19*, *20*), Miller (*23*), Rumm (*24*), Schander (*26*), and Sturgis (*29*).

MATERIALS AND METHODS

ENVIRONMENTAL CONDITIONS

The tomato plants used in the three experiments reported herein were grown in a fertile greenhouse soil at the Arlington Experiment Farm, Arlington, Va., during 1933 and 1934. The controlled factors were temperature, soil moisture, and the proportions of mineral nutrients. The fungicidal sprays studied were copper phosphate-bentonite-lime mixture, zinc sulfate-lime, and bordeaux mixture.

The experimental method used has been described in detail in previous papers (*13*, *14*). The tomato plants were grown at a number of different soil-moisture levels, which will be indicated later. Each of the experimental series was set up by first determining the original amount of water in the soil and then adding sufficient water to bring the water content up to the required percentage. After the seedlings had been transplanted to the crocks the soil moisture was maintained at approximately the desired level by frequent additions (four to six times daily) of measured amounts of water, the required amounts being determined by weighing the cultures on solution balances of 40-kg. capacity.

The plants used were similar to staked and pruned plants grown under field conditions. They were fruiting, large, and had heavy thick foliage. Figure 1 shows the very marked effect of temperature on the growth and habit of the tomato plants used in these experiments; all other conditions were uniform, with soil moisture at 86 percent of water-retaining capacity and with 12–6–12 fertilizer. Figure 2 shows the effect of soil moisture on plant growth and habit when other conditions were uniform.

Three crops of tomatoes were used in the experiments, and the experimental methods differed considerably in the three tests. For convenience in presenting the data, the three experiments will be designated as the copper phosphate, zinc-lime, and bordeaux mixture experiments, and the details will be given under these headings.

All plants in the three experiments were healthy and the fungicides were applied solely to determine their effect on the rate of transpiration.

COPPER PHOSPHATE EXPERIMENT

The copper phosphate experiment was conducted from March 3 to May 24, 1933, and the duration of the water-expenditure record was 82 days. The prespray period extended from March 3 to April 17, or 45 days, and was for the purpose of determining the relative tran-

[3] Cited by Miller (*23*, *p. 522*).
[4] Cited by Miller (*23*, *p. 507*).

spiration ratios of the paired plants before spraying. The spray period lasted from April 17 to May 24, or 37 days, during which time the effect of copper phosphate on the rate of transpiration was observed.

FIGURE 1.—Tomato plants showing influence of different temperatures on growth. Cultures grown at (*A*) 65°, (*B*) 70°, and (*C*) 74° F. All were grown at 86 percent of soil-water-retaining capacity and with 12–6–12 fertilizer.

This crop of tomatoes was grown in two different temperature units of the greenhouse (units 2 and 3), but because of rising outside temperatures the differences between the units decreased with time. During

the prespray period the mean temperature of unit 2 was 65.1° F. and that of unit 3 was 68.5°, a difference of 3.4°. During the spray period the mean temperature of unit 2 was 71.4° and that of unit 3 was 72.9°, a difference of only 1.5°. These data indicate a 6.3° mean-temperature difference between the prespray and the spray period for unit 2, and a 4.4° mean-temperature difference for unit 3.

In this experiment, a check and six fertilizer mixtures of the following formulas were used: 0–0–12, 0–6–6, 0–12–0, 6–0–6, 6–6–0, and

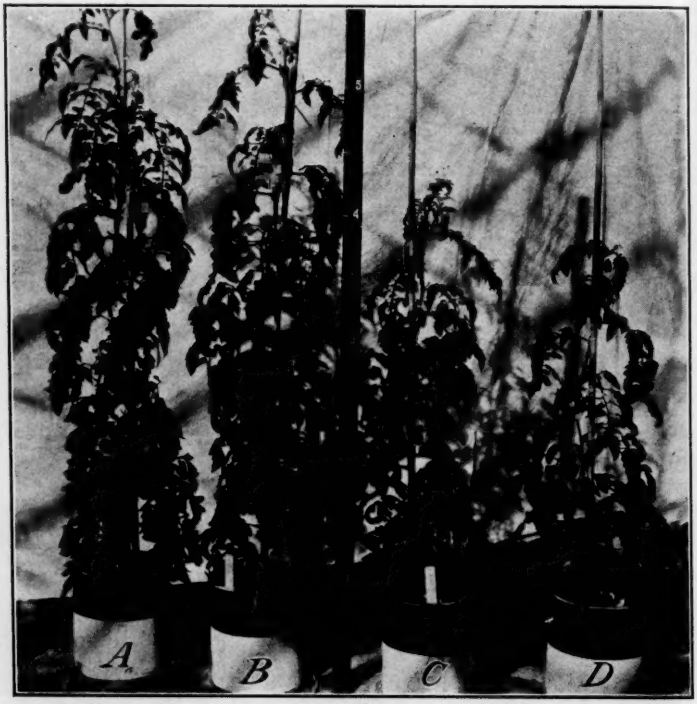

FIGURE 2.—Tomato plants showing influence of soil moisture on growth. Cultures grown at (*A*) 65, (*B*) 56, (*C*) 47, and (*D*) 39 percent of soil-water-retaining capacity. All were grown at 76° F. and with 12–2–2 fertilizer. Plants from a series grown in 1932.

12–0–0, the values in each formula representing nitrogen, phosphorus, and potassium, respectively; the check received no additional fertilizer. Five different soil-moisture levels were established and maintained at approximately 86, 77, 69, 60, and 51 percent of the water-retaining capacity of the soil. (See table 1.)

Single plants were grown in 3-gallon glazed crocks. Two crocks of each fertilizer treatment and of the check (receiving no additional fertilizer) were placed in each of the five soil-moisture series in each of the two different temperature units of the greenhouse. One plant of each pair was sprayed and the other was not, giving a treated (T) and a con-

trol (C) plant at each of the 70 points of observation, a total of 140 plants under approximately controlled environmental conditions.

This crop was sprayed with three applications at 10-day intervals during the 37 days of the spray period. The spray mixture consisted of 2 pounds of copper phosphate, 4 pounds of hydrated lime, and 2 pounds of bentonite, mixed and suspended in 50 gallons of water. Approximately 400 cc. of this mixture was applied to each treated plant at each of the three applications. In spraying, the plants were tipped at an angle to avoid application of the spray to the soil. Since the plants were always in the greenhouse, no spray residue was removed by rainfall.

ZINC-LIME EXPERIMENT

The zinc sulfate-lime experiment was conducted on a fall crop of tomatoes from November 23, 1933, to January 22, 1934, a period of 60 days. In this experiment, no prespray period was established since the cultures were of uniform size, permitting pairing at the beginning, one being sprayed and the other not sprayed.

Three fertilizer mixtures of the following formulas were used: 12–6–12, 12–0–12, and 6–12–6. Three soil-moisture levels were established: 86, 77, and 69 percent of the water-retaining capacity of the soil. The plants were grown under three different temperature conditions, and because of favorable outside temperature, inside temperature control was fairly constant. The mean temperatures for units 1, 2, and 3 were 76°, 71°, and 65° F., respectively.

Four crocks (single-plant cultures) of each fertilizer treatment were placed at each of the three soil-moisture levels in each of the three different temperature units of the greenhouse. Two of each of these were sprayed and two were not sprayed, giving two replications at each of the 54 points of observation and a total of 108 plants under well-controlled environmental conditions.

The tomato plants in this experiment were sprayed with a mixture of 4 pounds of zinc sulfate and 4 pounds of hydrated lime in 50 gallons of water. Three applications of this fungicide were made, each at the rate of 400 cc. per treated plant. The first application was made November 23, the date of the first water-expenditure record, and the succeeding applications 2 and 4 weeks later.

BORDEAUX MIXTURE EXPERIMENT

The bordeaux mixture experiment was also made upon a fall crop, the water-expenditure record beginning September 18 and ending December 1, 1934, extending over 74 days. The prespray period lasted 43 days, September 18 to October 31, 1934. The spray period was 31 days, from October 31 to December 1, 1934.

This experiment was different from the other two, as temperature was the only variable in the environment. The mean temperatures for units 1, 2, and 3, were 74°, 70°, and 66° F., respectively. A soil moisture of 72 percent of water-retaining capacity and a 6–12–6 fertilizer were used for the experiment. Three replications at each of the six points of observation gave for study a total of 18 plants.

This crop of tomatoes was sprayed with a 4–4–50 bordeaux mixture, 400 cc. to each treated plant. Three applications were made at 10-day intervals during the spray period.

TREATMENT OF DATA

The statistical procedure used by Duggar and Cooley (*9*, *10*) and adopted by Miller (*23*) and others for measuring the effect of fungicides upon the rate of transpiration of plants was followed in the computation and interpretation of the data presented in this work. This method was designed to remove the influence of all factors except those due to spray, i. e., the ratio between the transpiration from the treated and the control plant (T : C). In addition to the calculation of the transpiration ratios, the results of other statistical treatment of the data are also given, namely, the ratio of units of water transpired to the units of dry material produced above ground (water requirement); the water expended during the prespray, spray, and the entire experimental period. It is important to observe that the Duggar-Cooley and the analysis of variance computations appear to give consistent results; consequently either method is a valid basis for the interpretation of data.

Duggar and Cooley (*9*, *10*) divided their plants into two groups, designating those to be sprayed "T" (treated) and the control plants "C." These plants were paired and the transpiration ratio T′: C′ was determined before spraying. After the standardization period, the treated plants, T, were sprayed, and the ratio of the units of transpiration T : C was again determined for each pair of plants. If the ratio T : C had increased after spraying, the transpiration rate increase was presumed to be due to the application of the fungicide. If the ratio T : C had decreased, if the transpiration rate was less, or if it had not changed there was no apparent effect of the spraying on the transpiration rate. The third ratio T : C, which is a relative measure of the effect of spraying for the spray period, is then calculated by considering the ratio before spraying as 1.00.

In many of the experiments reported by other workers the amount of water transpired daily by the plants used was small, and the prespray and spray periods were of very short duration. Data obtained under such conditions are difficult to interpret and are not applicable to larger, older plants. To overcome these difficulties bearing plants were used (figs. 1 and 2) that transpired a large volume of water during daily periods, and the prespray and spray periods were extended over several weeks.

The amounts of water transpired over the entire period of observation by all the plants used in these experiments are of interest. During the prespray period of 45 days in the copper phosphate experiment, the average plant transpired a total of 18.3 liters of water; during the spray period of 37 days, 37.5 liters; and for the two periods, a total of 55.8 liters. These amounts are the means for 140 plants (treated and control groups), and if marked stimulation of transpiration had occurred, as has been frequently reported, the large amounts of water recorded would obviously be adequate to determine the different responses.

The tomato plants used in the other two experiments reported herein likewise transpired large amounts of water.

EFFECT OF FUNGICIDES ON TRANSPIRATION RATE OF TOMATO PLANTS

COPPER PHOSPHATE EXPERIMENT

The effect of copper phosphate on the rate of transpiration of tomato plants is illustrated in table 1, which shows the ratios of treated to control (T : C) plants during the prespray period, the spray period, the difference between periods, and the corrected ratio for the spray period. These data are listed under appropriate subheads for each level of soil moisture and each fertilizer under which the spray test was conducted. The application of Snedecor's (*28*) adaptation of the analysis of variance to the ratios (test to control) showed no significant effect of temperature, fertilizer, or soil moisture. However, the difference between the observed treatment mean (1.064) and a hypothetical control mean (1.000) shows the effect of copper phosphate-bentonite-lime spray to be a highly significant factor in increasing water expenditure by odds of more than 99 : 1 (table 2).

To test further the effects of copper phosphate spray on the rate of transpiration of tomato plants, data on the water transpired during the 37 days of the spray period and on the water requirement (total units of water transpired per unit of dry weight of aerial parts of plants) were analyzed by the variance method (table 2). In table 2 the significant effects of copper phosphate spray (test and control groups) on transpiration, and the highly significant effects of temperature, soil moisture, and fertilizer are clearly evident. The following interactions were significant: Temperature × moisture, temperature × fertilizer, and moisture × fertilizer. It is important also to note that there were no significant first-order interactions involving spray treatment, which indicates that the effect of copper phosphate on the rate of transpiration of tomato plants was not influenced significantly by the environments under these experimental conditions.

For the spray period the mean weight of water transpired by the sprayed plants was 38.4 liters and by the unsprayed, 36.7 liters; the mean dry weights were 77.4 gm. and 80.8 gm., respectively. The mean water requirements for the plants under the various conditions were as follows:

	Cc.
Sprayed	749
Unsprayed	703
Greenhouse unit 2 [1]	702
Greenhouse unit 3 [1]	750
At soil moisture percentage:	
86	826
77	735
69	702
60	710
51	658
With fertilizer mixture:	
No fertilizer	781
0–0–12	766
0–6–6	744
0–12–0	784
6–0–6	692
6–6–0	696
12–0–0	620

[1] For temperature of greenhouse unit, see p. 724.

TABLE 1.—*Transpiration ratios of control tomato plants and plants sprayed with copper phosphate when grown under different soil moisture and soil nutrient conditions in two different temperature units*

[For temperature of greenhouse unit, see p. 724.]

GREENHOUSE UNIT 2

Fertilizer formula	Transpiration ratios [1] of plants grown in soil of indicated moisture (percentage of saturation)																			
	86				77				69				60				51			
	T′:C′ before spray	T:C after spray	Relative increase [2]	Ratio increase [3]	T′:C′ before spray	T:C after spray	Relative increase [2]	Ratio increase [3]	T′:C′ before spray	T:C after spray	Relative increase [2]	Ratio increase [3]	T′:C′ before spray	T:C after spray	Relative increase [2]	Ratio increase [3]	T′:C′ before spray	T:C after spray	Relative increase [2]	Ratio increase [3]
Check	0.899	0.922	1.026	0.023	1.022	1.235	1.208	0.213	0.959	1.008	1.051	0.049	1.026	0.940	0.916	−0.086	0.901	1.033	1.147	0.132
0-0-12	.939	1.143	1.217	.204	[4].998	[4]1.016	[4]1.018	[4].018	.984	1.031	1.048	.047	1.040	1.026	.987	−.014	1.027	.948	.923	−.079
0-6-6	1.044	1.013	.970	−.031	.951	1.067	1.122	.116	1.014	1.192	1.176	.178	.973	1.033	1.062	.060	1.105	1.062	.961	−.043
0-12-0	.972	.963	.991	−.009	1.052	1.063	1.010	.011	1.031	1.114	1.081	.083	.918	.986	1.074	.068	1.017	1.081	1.063	.064
6-0-6	.781	.954	1.222	.173	[4].974	[4].992	[4]1.018	[4].018	.982	.981	.999	−.001	.761	1.129	1.484	.368	1.006	1.181	1.174	.175
6-6-0	1.118	1.134	1.014	.016	1.029	1.097	1.066	.068	.991	1.131	1.141	.140	1.060	1.071	1.010	.011	1.020	1.146	1.124	.126
12-0-0	.907	.985	1.086	.078	.934	.977	1.046	.043	.924	1.000	1.082	.076	[4]1.010	[4]1.082	[4]1.071	[4].072	.966	.930	.963	−.036

GREENHOUSE UNIT 3

Check	0.938	0.887	0.946	−0.051	1.019	0.756	0.742	−0.263	1.081	1.270	1.175	0.189	1.103	1.108	1.005	0.005	1.062	1.053	0.992	−0.009
0-0-12	1.178	1.100	.934	−.078	.891	1.019	1.144	.128	1.086	1.079	.994	−.007	.996	1.031	1.035	.035	.930	1.092	1.174	.162
0-6-6	1.006	.870	.865	−.136	1.004	1.058	1.054	.054	1.043	1.014	.972	−.029	.974	1.079	1.108	.105	.871	1.051	1.207	.180
0-12-0	1.191	1.347	1.131	.156	1.091	1.103	1.011	.012	.980	1.018	1.039	.038	1.001	1.105	1.104	.104	[4].980	[4]1.082	[4]1.104	[4].102
6-0-6	.874	1.065	1.219	.191	.969	1.120	1.156	.151	.973	1.016	1.044	.043	.981	1.163	1.186	.182	1.058	1.043	.986	−.015
6-6-0	.865	.988	1.142	.123	1.091	1.086	.995	−.005	1.014	1.036	1.022	.022	1.005	1.041	1.036	.036	.894	1.091	1.220	.197
12-0-0	1.150	1.133	.985	−.017	.966	.915	.947	−.051	.990	1.038	1.048	.048	1.015	.993	.978	−.022	.900	1.139	1.266	.239

[1] A difference of 0.340 between 2 ratios is considered significant by odds of 99 : 1.
[2] T : C :: T′ : C′ equals relative transpiration rate.
[3] Absolute increased transpiration ratios due to spray; minus signs indicate decrease.
[4] Control plants sprayed once by error.

TABLE 2.—*Analysis of variance of data showing the effect of copper phosphate spray on the transpiration ratio (T : C and T' : C', table 1), total water transpired during spray period, water requirement, and dry weight of tomato plants*

Source of variance	Degrees of freedom	Mean square for—			
		Transpiration ratios	Total water transpired	Water requirement	Dry weight of plants
Total	139	0.008,304	136.52	13,737	552.29
Between spray treatments	1	[1].123,018	[2] 108.98	[1] 74,199	[2] 389.44
Between temperatures	1	.009,578	[1] 1,145.37	[1] 76,332	[1] 773.62
Between moistures	4	.001,896	[1] 591.20	[1] 108,129	[1] 1,490.43
Between fertilizers	6	.009,459	[1] 2,027.77	[1] 72,035	[1] 8,430.13
Total interactions	127	.007,459	25.13	7,041	150.09
Spray treatments × temperatures	1	.001,872	.01	4,144	107.54
Spray treatments × moistures	4	.002,500	1.29	2,861	9.30
Spray treatments × fertilizers	6	.006,084	5.74	1,238	42.44
Temperatures × moistures	4	.008,154	[1] 23.63	11,910	25.40
Temperatures × fertilizers	6	.014,362	[2] 15.18	[2] 15,915	[2] 179.98
Moistures × fertilizers	24	.008,588	[1] 106.31	8,795	[1] 486.38
Remainder interactions (error)	82	.007,000	5.04	6,797	70.83

[1] Significant by odds of more than 99 : 1.
[2] Significant by odds of more than 19 : 1 but less than 99 : 1.

The application of the copper phosphate spray to tomato plants also had a highly significant effect on the water requirement of the plants as is indicated in table 2. It is of particular interest to note that the effects of copper phosphate, temperature, and fertilizer upon water requirement were of similar magnitude, all being highly significant. Soil moisture also had a highly significant effect. The only significant interaction observed was temperature × fertilizer. Since there was no significant interaction involving spray, it appears that in these studies the effect of spray on water requirement was entirely independent of these environmental factors.

Table 2 also gives a variance analysis of data showing the effects of copper phosphate spray and the environmental factors on the dry weight of the tomato plants. There were significant differences in the dry weights of the sprayed and of the control groups, and highly significant differences due to temperature, moisture, and fertilizer. Rather large interactions were observed for temperatures × fertilizers, and moistures × fertilizers, but there were no significant interactions involving spray treatments.

ZINC-LIME EXPERIMENT

The zinc sulfate-lime experiment differed from the other two experiments reported in this paper. There was no prespray period. The 108 plants were paired at the beginning of the experiment; 54 were sprayed with zinc-lime mixture and the remainder were used as controls. Furthermore, the plants in temperature units 1 to 3 (76°, 71°, and 65° F.) were harvested at different dates (22 days between the 76° and 65° F. lots). These differences in cutting dates interfere with close comparisons of temperature effects as measured by dry weights and total water expended divided by dry weights. However, the data permit the determination of the major effects of the several factors on transpiration during the 60-day period from November 23, 1933, to January 22, 1934.

The mean for the total water transpired was 33.5 liters for the sprayed plants and 33.9 liters for the unsprayed. The analysis of variance of the data on total water transpired during this period

(table 3) indicates that the application of zinc-lime spray had no effect. However, the differences due to temperature were very large; the effects of soil moisture and fertilizer were highly significant; and there were highly significant interactions for temperature × soil moisture, temperature × fertilizer, and soil moisture × fertilizer. There were no significant interactions involving spray treatment.

TABLE 3.—*Analysis of variance of data, based on the total water transpired, showing the effects of zinc-lime spray and environmental factors on the transpiration of 54 spray and 54 control plants during the period Nov. 23, 1933, to Jan. 22, 1934 (60 days)*

Source of variance	Degrees of freedom	Mean square for total water transpired
Total	107	164.88
Between spray treatments (treated and control)	1	4.24
Between temperatures	2	[1] 7,541.96
Between moistures	2	[1] 725.00
Between fertilizers	2	[1] 52.01
Temperatures × moistures	4	[1] 109.42
Temperatures × fertilizers	4	[1] 20.11
Moistures × fertilizers	4	[1] 25.53
Spray treatments × temperatures	2	2.17
Spray treatments × moistures	2	8.26
Spray treatments × fertilizers	2	2.25
Remainder interactions (error)	82	4.32

[1] Significant by odds of more than 99 : 1.

To show further the effects of zinc-lime spray mixture on the rate of transpiration of tomato plants, analysis of variance is given in table 4 for data on "water requirement" (ratio of total units (cubic centimeters) of water transpired to total units (grams) gain in dry weight of aerial part of plant). This table contains data relating to the high-temperature (76° F.) greenhouse unit only. The results showing the effects of spray in the other two units were in agreement with those in unit 1. Data from all three temperature units were not combined in a single analysis of variance because of the differences in stage of development accompanying different harvest dates. The mean water requirement for the sprayed plants was 581 cc. per gram of increase in dry weight, and for the control 612 cc., an insignificant difference. The effect of soil moisture on water requirement also was not significant in this experiment, but fertilizer had a very marked effect which was highly significant. If zinc-lime spray had influenced the rate of transpiration (see table 4), this effect probably would have been reflected in the water requirement data.

TABLE 4.—*Analysis of variance of data on water requirement showing the effects of zinc-lime mixture in the high-temperature unit (76° F.)*

Source of variance	Degrees of freedom	Mean square
Total	35	4,667
Between spray treatments (test and control)	1	8,311
Between moistures	2	6,793
Between fertilizers	2	[1] 32,866
Total interactions	30	2,524
Spray treatments × moistures	2	3,591
Spray treatments × fertilizers	2	1,610
Moistures × fertilizers	4	3,464
Remainder interactions	22	2,338

[1] Significant by odds of more than 99 : 1.

BORDEAUX MIXTURE EXPERIMENT

The results of the bordeaux mixture experiment are presented in table 5. They show the effects of the treatment on the transpiration ratio of tomato plants under the experimental conditions described. A variance analysis of T: C before and after spraying is given in table 6. The mean T: C for the first (prespray) period was 1.029; for the second (spray) period 1.010; and the mean for the ratio between the two periods, 0.982. A hypothetical mean of 1.000 would indicate no change; although the value 0.982 might suggest a depression of the transpiration rate following spraying, the difference is not significant (table 6).

Additional data show further that bordeaux mixture does not affect the rate of transpiration of mature tomato plants appreciably. The mean water transpired per plant during the spray period by the treated plants was 27.4 liters and by the control plants 27.3 liters. The mean dry weight of the treated plants was 82.4 gm. and that of the controls 82.1 gm., the total water expended was 50.0 and 49.4 liters, respectively, and the mean water requirement 614 cc. and 610 cc., respectively.

TABLE 5.—*Effect of bordeaux mixture on the transpiration ratio of 9 pairs of sprayed and control plants, Sept. 18 to Dec. 1, 1934 (74 days)*

Temperature (°F.)	Transpiration ratio			
	T′: C′ before spray	T: C after spray	Relative increase [1]	Ratio increase [2]
74	1.043	1.002	0.961	−0.041
	1.022	.961	.940	−.061
	.945	.982	1.039	.037
70	.954	1.061	1.112	.107
	.963	.958	.995	−.005
66	1.086	.917	.844	−.169
	1.164	1.127	.968	−.037
	1.008	1.025	1.017	.017
	1.079	1.059	.981	−.020

[1] T : C :: T′: C′ equals relative transpiration rate.
[2] Absolute increased transpiration ratios due to spray; minus signs indicate decrease.

TABLE 6.—*Analysis of variance of data showing the effect of bordeaux spray on total water transpired, dry weight, water requirement, and transpiration ratio (T: C and T′: C′, table 5) of plants*

Source of variance	Degrees of freedom	Mean square for—			
		Total water transpired	Dry weight of plants	Water requirement	Transpiration ratio
Total	17	37.78	68.92	12,140	0.004521
Between spray treatments	1	1.65	.35	61	.001643
Between temperatures	2	[1] 296.63	[2] 221.55	[1] 87,627	[2] .014746
Spray treatments × temperatures	2	6.84	24.69	3,697	.000038
Remainder (error)	12	2.80	56.56	1,973	.003803

[1] Significant by odds of more than 99 : 1.
[2] Significant by odds of more than 19 : 1.

In table 6 data are given showing the lack of significance of the effect of bordeaux mixture on the total water transpired, dry weight of the plants, and water requirement. However, temperature differences

had a highly significant effect on total water transpired and the water requirement, and a significant effect on the dry weight of the plants. It is of particular interest to note that there were no significant interactions of spray × temperature.

Table 7 gives an analysis of variance of the data for the water transpired during the spray period and also during the prespray period. In each test period there was no significant difference in the quantity of water transpired between the two groups of plants (spray and control). Temperature, however, had a highly significant effect. These data on rate of transpiration further indicate that bordeaux mixture had no effect regardless of the method used in attempting to measure effect.

TABLE 7.—*Analysis of variance of data for total water transpired for the prespray and spray periods, showing the effect of bordeaux spray and temperature*

Source of variance	Degrees of freedom	Mean square for water transpired—	
		Prespray period	Spray period
Total	17	4.81	17.28
Between spray treatments	1	1.16	.04
Between temperatures	2	[1] 32.09	[1] 135.73
Spray treatments × temperatures	2	1.22	2.28
Remainder (error)	12	1.17	1.48

[1] Significant by odds of more than 99:1.

DISCUSSION

The tomato plants used in all three experiments reported in this paper were healthy and free from all traces of parasitic or virus diseases. The three fungicides used were applied solely to determine their effects on rate of transpiration of the respective cultures. All the plants used were large and fruitful, with heavy thick leaves, and they showed a fairly large loss of water over daily periods.

Miller (*23*) and Childers (*6*) were apparently the first two investigators to attempt to determine the effect of bordeaux mixture on the rate of transpiration of mature tomato plants that were grown under conditions favorable to a high rate of transpiration. Both workers reported that bordeaux mixture either had no effect on or actually caused a reduction in the rate of transpiration. They did not attempt to determine the interaction between the effects of spray and other environmental variables (concurrently) on the rate of transpiration of their plants. The present studies confirm and extend the applicability of those results.

In tables 1 and 2 data are given that indicate definitely that copper phosphate-bentonite-lime mixture, when applied as a fungicide, caused a highly significant increase in the rate of transpiration of mature plants. This definite increase in rate of water expenditure occurred regardless of how the increase was calculated. It is of special interest that there was no significant interaction between effect of spray and the other environmental variants. The response to spraying was consistent regardless of the cultural conditions. The data on total water transpired and water requirement basis also

indicated a definite increase in water utilization after the application of copper phosphate-bentonite spray. It has not been determined whether copper phosphate or bentonite or both substances were responsible for the results observed.

Very little is known about the effects of bentonite. This fact should be kept in mind before too definite conclusions are attempted with reference to the effect of copper phosphate on transpiration. The zinc-lime and bordeaux mixtures did not contain bentonite.

SUMMARY

In this report data are presented that show the effect of copper phosphate-bentonite-lime, zinc-lime, and bordeaux mixture on the rate of transpiration of large, fruiting tomato plants (*Lycopersicon esculentum* Mill.). Extensive data are also presented which show the lack of interaction of these fungicides under widely different environmental conditions on the rate of transpiration of tomato plants, and indicate that environment does not influence the effect of the spray mixtures on the transpiration.

Copper phosphate-bentonite-lime, applied as a fungicide, caused a significant increase in the rate of transpiration of mature tomato plants.

Zinc-lime and bordeaux mixture had no significant effect on the rate of transpiration under the experimental conditions reported.

Added increments of soil nitrogen, reduced soil moisture, and reduced air temperature all caused a marked reduction in rate of transpiration.

LITERATURE CITED

(1) Bain, Samuel M.
1902. The action of copper on leaves, with special reference to the injurious effects of fungicides on peach foliage: a physiological investigation. Tenn. Agr. Expt. Sta. Bul. 15, 108 pp., illus.

(2) Bayer, L.
1902. Beitrag zur pflanzenphysiologischen bedeutung des kupfers in der bordeauxbrühe. Diss., 56 pp. Königsberg.

(3) Bonde, Reiner.
1932. Potato spraying and dusting experiments 1929 to 1931. Maine Agr. Expt. Sta. Bul. 362, pp. 177–232, illus.

(4) ———
1934. Stimulation of potatoes by magnesium bordeaux spray. (Abstract) Phytopathology 24: 3.

(5) Butler, O.
1922. Bordeaux mixture II. stimulatory action. N. H. Agr. Expt. Sta. Tech. Bul. 21, 50 pp.

(6) Childers, Norman F.
1936. Some effects of sprays on the growth and transpiration of tomatoes. Amer. Soc. Hort. Sci. Proc. 33: 532–535.

(7) Clinton, G. P.
1911. Spraying potatoes in dry seasons. Conn. (State) Agr. Expt. Sta. Bien. Rpt. 1909–10: 739–752.

(8) Duggar, B. M., and Bonns, W. W.
1918. The effect of bordeaux mixture on the rate of transpiration. Mo. Bot. Gard. Ann. 5: 153–176, illus.

(9) ——— and Cooley, J. S.
1914. The effect of surface films and dusts on the rate of transpiration. Mo. Bot. Gard. Ann. 1: 1–22, illus.

(10) ——— and Cooley, J. S.
1914. The effects of surface films on the rate of transpiration: experiments with potted potatoes. Mo. Bot. Gard. Ann. 1: 351–356, illus.

(11) Dutton, W. C., and Wells, H. M.
[1924.] some physiological effects of bordeaux. Amer. Soc. Hort. Sci. Proc. 20: 277–281.
(12) Ewert, [Richard].
1905. der wechselseitige einfluss des lichtes und der kupferkalkbrühen auf den stoffwechsel der pflanze. Landw. Jahrb. 34: 233–310, illus.
(13) Foster, Arthur C., and Tatman, E. C.
1937. the influence of soil moisture and fertilizers on the specific electrical conductivity of tomato plant sap. Amer. Jour. Bot. 24: 35–39, illus.
(14) ——— and Tatman, Everett C.
1938. influence of certain environmental conditions on congestion of starch in tomato plant stems. Jour. Agr. Res. 56: 869–881, illus.
(15) Frank, B., and Krüger, F.
1894. ueber den reiz, welchen die behandlung mit kupfer auf die kartoffelpflanze hervorbringt. Deut. Bot. Gesell. Ber. 12: 8–11.
(16) ——— and Krüger, F.
1894. über den direkten einfluss der kupfer-vitriol-kalk-brühe auf die kartoffelpflanze. Deut. Landw. Gesell. Arb. 1894, No. 2, 46 pp., illus.
(17) Horsfall, James G., and Harrison, A. L.
1939. effect of bordeaux mixture and its various elements on transpiration. Jour. Agr. Res. 58: 423–443, illus.
(18) Krausche, Kenneth K., and Gilbert, Basil E.
1937. increase of transpiration rates of tomato leaves due to copper sprays. Plant Physiol. 12: 853–860.
(19) Lutman, B. F.
1916. some studies on bordeaux mixture. Vt. Agr. Expt. Sta. Bul. 196, 80 pp., illus.
(20) ———
1919. tip burn of the potato and other plants. Vt. Agr. Expt. Sta. Bul. 214, 28 pp., illus.
(21) Martin, William H.
1916. influence of bordeaux mixture on the rates of transpiration from abscised leaves and from potted plants. Jour. Agr. Res. 7: 529–548.
(22) ——— and Clark, E. S.
1929. influence of bordeaux mixture on transpiration. N. J. Agr. Expt. Sta. Ann. Rpt. 50: 249–255, illus.
(23) Miller, E. C.
1938. plant physiology with reference to the green plant. Ed. 2, 1201 pp., illus. New York and London.
(24) Rumm, C.
1893. ueber die wirkung der kupferpräparate bei bekämpfung der sogenannten blattfallkrankheit der weinrebe. Deut. Bot. Gesell. Ber. 11: 79–93.
(25) Runnels, H. A., and Wilson, J. D.
1934. the influence of certain spray materials, herbicides, and other compounds on the desiccation of plant tissue. Ohio Agr. Expt. Sta. Bimo. Bul. 19: 104–109.
(26) Schander, Richard.
1904. über die physiologische wirkung der kupfervitriolkalkbrühe. Landw. Jahrb. 33: [517]–584, illus.
(27) Shive, John W., and Martin, William H.
1917. the effect of surface films of bordeaux mixture on the foliar transpiring power in tomato plants. Plant World 20: 67–86, illus.
(28) Snedecor, George W.
1937. statistical methods applied to experiments in agriculture and biology. 341 pp., illus. Ames, Iowa.
(29) Sturgis, Wm. C.
1895. notes on the "early blight" of potatoes. Conn. (State) Agr. Expt. Sta. Ann. Rpt. (1894) 18: 127–133.

(30) WILSON, J. D., and RUNNELS, H. A.
1935. EFFECT ON TRANSPIRATION OF VARYING THE COPPER-LIME RATIO IN BORDEAUX MIXTURES. Ohio Agr. Expt. Sta. Bimo. Bul. 20: 206–209.
(31) ——— and RUNNELS, H. A.
1937. FIVE YEARS OF TOMATO SPRAYING. Ohio Agr. Expt. Sta. Bimo. Bul. 22: 13–20.
(32) ——— and RUNNELS, H. A.
1937. THE EFFECT OF VARIOUS SPRAY MATERIALS ON TOMATO TRANSPLANTS. Ohio Agr. Expt. Sta. Bimo. Bul. 22: 58–65, illus.
(33) ZUCKER, A.
1896. BEITRAG ZUR DIREKTEN BEEINFLUSSUNG DER PFLANZEN DURCH DIE KUPFER-VITRIOL-KALKBRÜHE. Diss., 88 pp. Stuttgart.

THE CHLOROFORM-SOLUBLE COMPONENTS OF BEET LEAFHOPPERS AS AN INDICATION OF THE DISTANCE THEY MOVE IN THE SPRING[1]

By ROBERT A. FULTON, *associate entomologist*, and VAN E. ROMNEY, *assistant entomologist, Division of Truck Crop and Garden Insect Investigations, Bureau of Entomology and Plant Quarantine, United States Department of Agriculture*

INTRODUCTION

Determination of the spring breeding areas from which beet leafhoppers (*Eutettix tenellus* (Bak.)) found in a cultivated district have come has presented a difficult problem. The most common method has been to make sweep-net collections from host plants at points between the infested territory and the suspected breeding areas.[2] Various types of traps [3] [4] have also been used with fair success. The sex ratio of adults has proved useful in some localities, since female leafhoppers have been found to move farther from their breeding source than do males.[5] More recently the amount of reserve energy of the beet leafhopper, as measured by its chloroform-soluble components, has been studied by a method developed by the senior author;[6] and determinations on leafhoppers collected at various points along dispersal routes indicate that these components decrease during flight, and may therefore be used as a measure of the distance the leafhoppers have traveled from their breeding source.

This paper reports studies of the chloroform extractives of female beet leafhoppers following dispersals from the Colorado River drainage northeastward into western Utah in 1932 and from southern Arizona to Grand Valley, Colo., in 1933, both representing long-distance dispersals, and following a dispersal in southern Idaho in 1932, 1933, and 1934, representing more localized movements.

EXPERIMENTAL PROCEDURE

The insects were collected along the suspected routes by means of a sweep net, and were immediately killed with calcium cyanide. They were then placed between pieces of crepe paper in small pill boxes and shipped to the laboratory, where the sexes were separated and the females analyzed for chloroform-extractive content. Three determinations were made on each sample except in two instances, when the sample was too small and only two determinations could be made.

[1] Received for publication June 11, 1940. The senior author is now chemist in the Division of Insecticide Investigations.

[2] DORST, H. E., and DAVIS, E. W. TRACING LONG-DISTANCE MOVEMENTS OF BEET LEAFHOPPER IN THE DESERT. Jour. Econ. Ent. 30: 948–954, illus. 1937.

[3] FULTON, F. R., and CHAMBERLIN, JOSEPH C. A NEW AUTOMATIC INSECT TRAP FOR THE STUDY OF INSECT DISPERSION AND FLIGHT ASSOCIATIONS. Jour. Econ. Ent. 24: 757–761, illus. 1931.

[4] BARNES, DWIGHT F., FISHER, CHARLES K., and KALOOSTIAN, GEORGE H. FLIGHT HABITS OF THE RAISIN MOTH AND OTHER INSECTS AS INDICATED BY THE USE OF A ROTARY NET. Jour. Econ. Ent. 32: 859–863, illus. 1939. A trap devised by F. R. Lawson and J. C. Chamberlin is described.

[5] SEVERIN, HENRY H. P. LIFE-HISTORY OF BEET LEAFHOPPER, EUTETTIX TENELLUS (BAFER), IN CALIFORNIA. Calif. Univ. Pubs., Ent. 5: 37–88, illus. 1930.

[6] FULTON, ROBERT A. DETERMINATION OF CHLOROFORM EXTRACT OF BEET LEAFHOPPER. A MICROMETHOD. Indus. and Engin. Chem., Analyt. Ed. 9: 437–438, illus. 1937.

LONG-DISTANCE MOVEMENTS

In 1932 beet leafhoppers were collected at various points in western Utah between St. George and Nephi, a distance of 205 miles (fig. 1).[7] St. George is at the extreme northern limit of the Nevada-Utah breeding area, and the other collections were made in areas infested by movement from this area. These collections were made May 17–19, shortly after a dispersal had taken place. It has been observed that no increase in chloroform extractives can be detected for 5 to 7 days

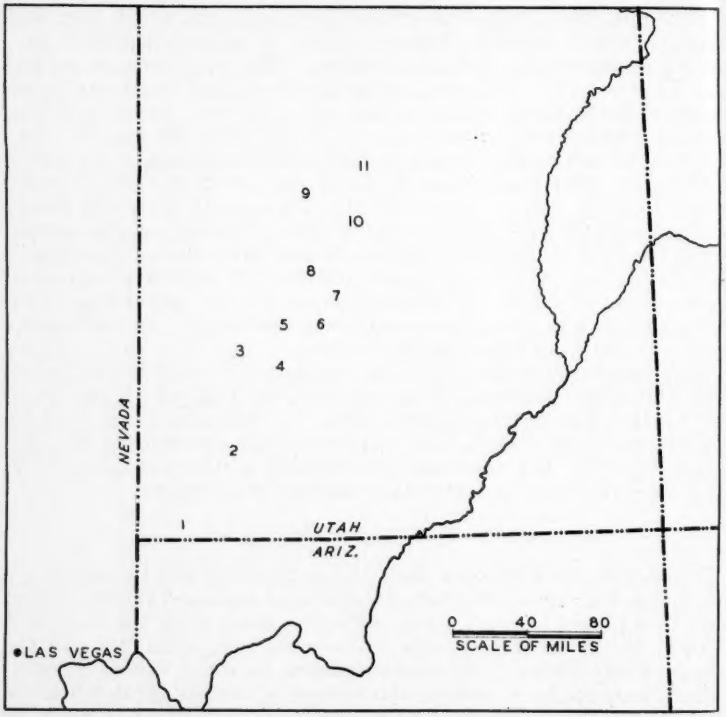

FIGURE 1.—Location of points where beet leafhoppers were taken along the western Utah dispersal routes during May 1932. Numbers refer to collection points designated in table 1.

after a dispersal. The sweep-net collections and the average chloroform-extractive contents, together with the distances from Las Vegas, Nev., a convenient point within the breeding area, are given in table 1.

Both the sweep-net collections and the chloroform extractives were in general greatest near the breeding area, and decreased progressively with the distance from the source. Collections 6 and 7 did not follow this trend, however, possibly because additional energy was required

[7] These data were collected by E. W. Davis, and the dispersal route is that shown by Dorst and Davis (see footnote 2).

in entering the valley over surrounding high mountains, or because many of the leafhoppers came from a more distant source or by a less direct route. The chloroform extractives of leafhoppers within the Utah, Nevada breeding area ranged between 38 and 46 percent; therefore, these determinations indicate that the source of these leafhoppers was quite distant.

TABLE 1.—*Sweep-net collections and the chloroform extractives of beet leafhoppers within the Nevada-Utah breeding area, and at various distances from this area, May 17–19, 1932*

Collection No.	Locality (Utah)	Airline distance from Las Vegas, Nev.	Mean leafhoppers per 100 sweeps		Chloroform extractives
			Adults	Nymphs	
		Miles	*Number*	*Number*	*Percent*
1	St. George	110	50.0	28.0	38.4
2	Cedar City	158	39.0	0	22.8
3	Milford	200	46.0	0	14.9
4	Beaver	206	18.0	0	15.7
5	Cove Fort	222	12.0	0	14.1
6	Sevier	238	22.7	0	8.7
7	Richfield	252	5.0	0	9.3
8	Fillmore	255	10.5	0	13.1
9	Lyndyl	286	11.0	0	11.1
10	Fayette	288	2.0	0	10.6
11	Nephi	315	4.0	0	8.9

In 1933 another set of samples for extraction was taken along a route between southern Arizona and the Grand Valley of Colorado (fig. 2), where survey work the previous year had given indications of leafhopper movements. At points along this route 18 collections were made from April 24 to 29, as soon as the first insects dispersed had reached the more northern points. The sweep-net and chloroform-extractives data for these collections are given in table 2.[8] The approximate distances were measured from Phoenix, Ariz., a convenient point in the breeding area.

TABLE 2.—*Sweep-net collections and the chloroform extractives of beet leafhoppers within the southern Arizona breeding areas and at intermediate points toward Grand Valley, Colo., April 24–29, 1933*

Collection No.	Locality	Airline distance from Phoenix, Ariz.	Mean leafhoppers per 100 sweeps		Chloroform extractives
			Adults	Nymphs	
		Miles	*Number*	*Number*	*Percent*
1	Marinette, Ariz.	15	520.0	20.0	41.5
2	4 miles southeast of Wittmann, Ariz.	35	156.0	24.0	42.4
3	Morristown, Ariz.	43	8.3	3.0	46.3
4	2.4 miles south of Wickenburg, Ariz.	52	68.0	28.0	39.5
5	3.2 miles south of Paulden, Ariz.	105	82.4	0	28.4
6	Ashfork, Ariz.	130	24.8	0	29.4
7	Seligman, Ariz.	145	2.5	0	28.9
8	2.8 miles southwest of Tuba City, Ariz.	205	30.4	0	27.6
9	6.2 miles south of Cedar Ridge, Ariz.	215	29.6	0	25.5
10	17.7 miles northeast of Tuba City, Ariz.	217	10.4	0	26.3
11	Tonalea, Ariz.	222	20.8	0	25.7
12	Kayenta, Ariz.	255	6.4	0	24.8
13	2.2 miles northeast of Mexican Hat, Utah	300	4.8	0	23.1
14	Blanding, Utah	335	4.0	0	22.6
15	Notum, Utah	350	.6	0	19.6
16	Hanksville, Utah	362	1.3	0	17.8
17	5.5 miles east of Thompsons, Utah	415	2.0	0	15.4
18	Grand Valley, Colo.	450	.7	0	6.6

[8] Some of the data shown in table 2 were collected by W. A. Shands, who was at that time in charge of the Grand Junction, Colo., field laboratory of this Bureau.

The first four collections were made on different host plants within the breeding source, and the average chloroform-extractive content was 42.4 percent. Between collections 6 and 17 there was a fairly regular decrease in chloroform extractives with the increase in the distance from the breeding source. Collection 18 seems to be low,

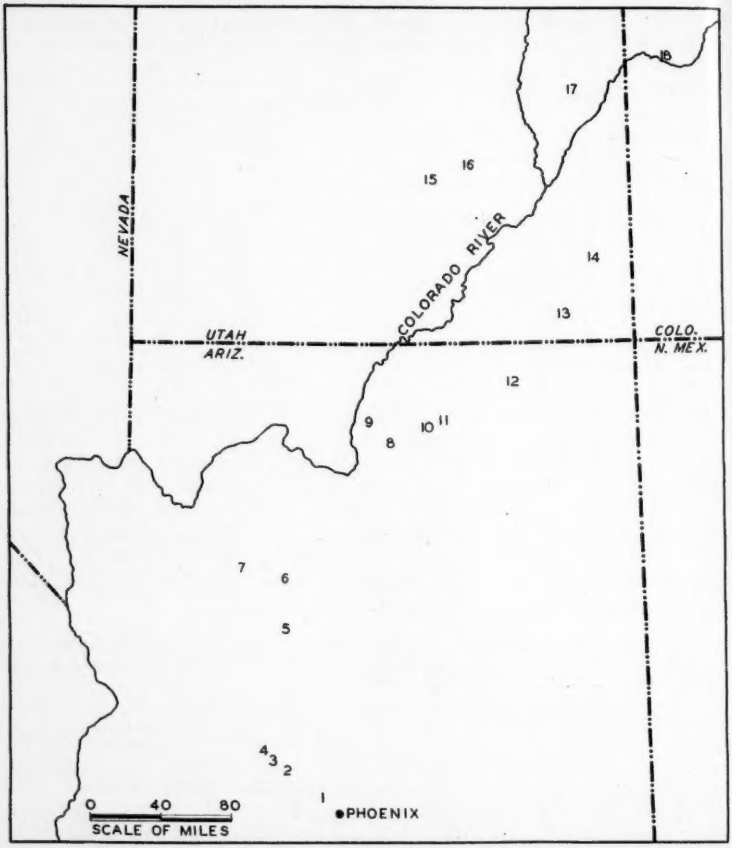

FIGURE 2.—Location of collections of beet leafhoppers taken along the Colorado drainage route during April 1933. Numbers refer to collection points designated in table 2.

since the drop from 15.4 to 6.6 percent in extractives within a distance of 35 miles seems out of line. Collections 6 to 18 also indicate in a general way that the leafhoppers decrease in number as the distance from the breeding source increases, although the sweep-net data are not nearly so consistent as those for the chloroform extractives.

LOCALIZED MOVEMENTS

In southern Idaho the cultivated beet districts have been considered to be infested with leafhoppers from adjacent breeding areas,[9] and this belief has been substantiated by a study of the chloroform extractives of females collected immediately after dispersals into these cultivated districts over a 3-year period. The data for 1932 in table 3 show the extractives of females from 4 points within the breeding area and from 17 infested beet fields in the Twin Falls-Jerome district (fig. 3). The closeness between the figures for the breeding areas and the beet fields indicates that the local breeding areas were responsible

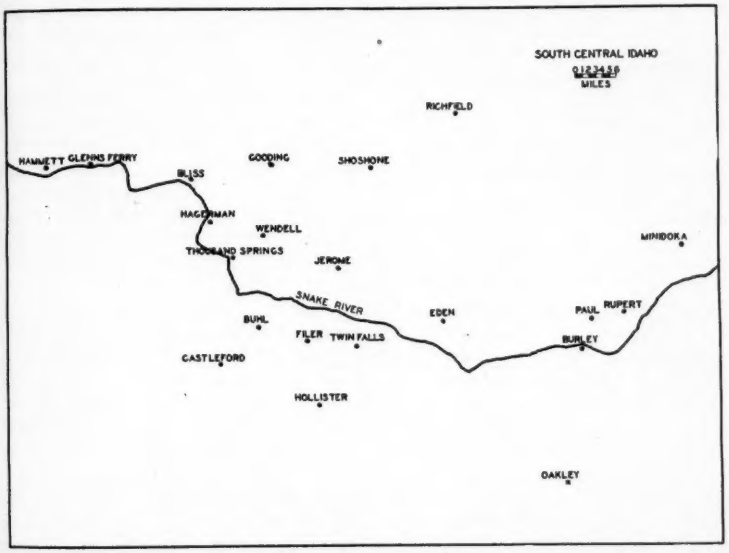

FIGURE 3.—Map of south-central Idaho showing towns near which collections were made in the desert breeding areas and in the beet fields.

for leafhoppers found in the southern Idaho beet fields following this movement.

The studies were repeated in the spring of 1933, collections being made at various localities in the western breeding areas, extending from Wendell to Glenns Ferry, Idaho, and also from the beet fields throughout the west end of the cultivated section. Collections in the east end were not taken at this time, inasmuch as the dispersing leafhoppers were extremely scarce and had not been detected east of Filer. The collections from the beet fields (Castleford, Buhl, and Wendell) were made as soon as the first influx of leafhoppers was detected (June 7–10). The results of the determinations are shown

[9] ANNAND, P. N., CHAMBERLIN, J. C., HENDERSON, C. F., and WATERS, H. A. MOVEMENTS OF THE BEET LEAFHOPPER IN 1930 IN SOUTHERN IDAHO. U. S. Dept. Agr. Cir. 244, 24 pp., illus. 1932.

in table 3. The slight decrease in chloroform-extractive content of the leafhoppers collected in the beet fields indicates a very near source for the 1933 infestation.

TABLE 3.—*Chloroform extractives of female beet leafhoppers collected shortly after the main influx into the beet-growing district in southern Idaho in 1932, 1933, and 1934*

Location of collection	Chloroform extractives from collections		
	1932	1933	1934
IN BREEDING AREA			
	Percent	*Percent*	*Percent*
2 miles south 1 mile west of Hagerman	38.6		
Thousand Springs	38.4		20.3
5.5 miles south of Thousand Springs	38.5		
4 miles north 7 miles west of Hollister	38.4		
1 mile west of Hammett			29.9
2 miles east of Hammett		34.7	
Glenns Ferry			26.4
2.2 miles west of Glenns Ferry		35.1	29.1
3 miles east of Glenns Ferry		34.6	
1 mile north 7 miles west of Castleford			26.3
7 miles west of Castleford		35.6	
1 mile south 4 miles west of Bliss		35.3	
Bliss			21.9
Average	38.5	35.1	25.7
IN BEET FIELDS			
1 mile south 1 mile west of Castleford	38.4		
3 miles south of Castleford	38.4		
4 miles south ¼ mile west of Castleford			17.1
5 miles east of Castleford	38.3		
1 mile east of Buhl		33.5	
1.5 miles east of Buhl	38.5		
4.5 miles east of Buhl	38.3		
3 miles north of Buhl	38.2	33.9	
2 miles south 4 miles west of Twin Falls	37.7		
2 miles west 2 miles north of Twin Falls	38.0		
4 miles west of Twin Falls	37.7		
Eden	36.9		
2 miles south 1 mile west of Burley	37.4		
2 miles west of Jerome		34.2	18.9
4 miles north 2 miles east of Jerome	38.3		
4 miles west 2 miles south of Jerome		33.7	
4.5 miles west of Jerome	38.4		
0.5 mile north of Paul	37.5		
4 miles east 2 miles south of Jerome	37.2		
8 miles north of Oakley	38.2		
1 mile west 2 miles north of Oakley	37.9		
1 mile south 2.5 miles east of Wendell			19.6
1 mile south 3 miles west of Wendell		34.1	
2 miles south ¼ mile west of Gooding			21.4
2 miles east 2¼ miles south of Jerome			17.8
5 miles south 3 miles east of Buhl			17.3
0.5 mile north of Filer			16.9
Average	38.0	33.9	18.4

Collections from Thousand Springs to Hammett and also from the western section of the beet-growing district were studied in the spring of 1934. These collections were made on May 10–11, about 2 weeks after the beginning of the movement and prior to its peak. The chloroform extractives found in these leafhoppers are given in table 3. The same relationship between the extractive content of leafhoppers taken in the breeding area and that of leafhoppers in the beet fields was maintained in that year, but both were decidedly lower than in 1932 and 1933. Either host-plant conditions or some unknown

factors caused the leafhoppers in the breeding area to have a comparatively low extractive content, or leafhoppers from a more distant source infested both the breeding areas and the beet fields.

CONCLUSION

There appears to be a steady reduction in the chloroform-soluble material of the leafhoppers as they move along an extended migration route away from the breeding area, but only a small variation where localized or short-distance flights occur. It seems possible, therefore, by extraction of individuals collected over sufficient area during a flight of insects to determine whether it is a local or a long-distance dispersion.

SUMMARY

The chloroform-soluble components of the beet leafhopper (*Eutettix tenellus* (Bak.)) have been studied as a means of determining the distance leafhoppers found in cultivated fields have traveled from their breeding source. The beet leafhoppers were collected at various points along dispersal routes and analyzed by a method developed by the senior author.

In 1932 the collections were made along a known long-distance dispersal route from the Colorado River drainage in Nevada northeastward into western Utah, and in 1933 along another suspected route from southern Arizona to Grand Valley, Colo. In 1932, 1933, and 1934 collections were also made in southern Idaho, where more localized movements were suspected.

Along the first route the percentage of total extractives decreased from 38.4 in leafhoppers taken at the point nearest the breeding source to 8.9 in leafhoppers taken at the farthest point, 205 miles away, and along the second route the percentage decreased from 39.5 to 6.6 over a distance of 398 miles. In southern Idaho the chloroform extractives of leafhoppers collected in the breeding areas were 38.5, 35.1, and 25.7 percent for the 3 years, respectively, as compared with 38.0, 33.9, and 18.4 percent in the beet fields. The closeness of the figures for the two areas indicates that the beet-growing districts of southern Idaho are infested principally from adjacent breeding grounds.

The chloroform extractives show a more consistent decrease as distance from the breeding source increases than do sweep-net counts of the insects, although the data corroborate each other. It seems possible, therefore, to distinguish between long-distance and local dispersions by determining the chloroform extractives of the leafhoppers collected along the known or suspected dispersal routes.

INHERITANCE OF SEED-COAT COLOR IN PEANUTS [1]

By B. B. HIGGINS

Botanist, Georgia Agricultural Experiment Station

INTRODUCTION

The principal seed-coat colors in the peanut (*Arachis hypogaea* L.) are due to water-soluble pigment or pigments, and the colors fade rapidly from mature peanuts left in moist soil and more slowly from those in dry storage. Frequently, seed from a single plant may show a wide range in intensity or shade of color because of fading and differences in stage of maturity; so that much confusion in regard to color nomenclature is found in the literature.

MATERIALS AND METHODS

The present discussion is based upon records of general characteristics of some 85 varieties and strains and of hybrid stocks developed from crosses among 16 of these varieties. In recording testa color, the color standards of Société Francaise des Chrysanthémistes (*4*) [2] have been found most convenient, as the relationship of the various tones and shades could be demonstrated. By the use of these standards the testa colors of the varieties and strains were separated readily into three color groups, red, flesh, and white. However, a pure self-color is rare in the harvested seed of any variety.

In the flesh-colored varieties the base color is usually salmon flesh, but it may vary from pale flesh to dark flesh. Usually pale reddish-lilac markings are found about the hilum end and along the veins and may spread as a flush over a large part of the seed, as it does typically in the Virginia Runner and the Virginia Bunch varieties. Occasionally, a violet flush may show about the tips of a few seeds or, rarely, may spread over the entire surface. This violet flush is most common on the seed from small pods, "nubbins" of the shellers, produced in the crown of the plant and more or less exposed to light. This exposure may account for the unusual pigmentation.

Of the varieties commonly grown in this country, the Spanish, North Carolina Runner (African), Virginia Runner, and Virginia Bunch are classed as "flesh" in the writer's grouping. Hull (*2*) found a genetic difference between the "russet" of Virginia Bunch and the "tan" of a Spanish strain. There are various shades of flesh, when compared with color standards, within the Spanish variety; but all appear to segregate similarly when crossed with a variety from the red or white color group. Intensity of flesh color and the reddish-lilac flush about the tip are undoubtedly inherited characteristics; but the genetic factors producing them appear to be separate from the factors responsible for the base color, and for the purpose of color grouping all these various shades are here classed as flesh.

[1] Received for publication March 7, 1940. Paper No. 70, Journal Series, Georgia Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 752.

The reds place typically about salmon lilac or Indian lake of the color standards; but seed from a single plant may range from pale reddish lilac through reddish lilac, salmon lilac, or Indian lake to vinous purple or even slate violet. When mature red seed are wet, the color usually fades to slate violet. In a few hybrid strains the color is typically slate violet, but these are classed with the reds because this color appears to be common to all red varieties. Vinous purple appears to bear the same relation to red seed as does violet to flesh colored. The purple is most pronounced about the hilum tip, apparently the result of a mixture of violet and red pigments. Neither in the writer's variety collection nor among his hybrid stocks have any been found in which all seeds were vinous purple.

Patel, John, and Seshadri (*5*) have recently reported the genetics of several seed-coat colors, including a "dark purple" as found in the Corientes–3 variety. They found purple testa dominant to red, "rose" (flesh), and white; that Corientes–3 carries the factor for "rose"; and that "rose" is necessary for the expression of purple. This variety is not included in the writer's collection.

The variety collection used in the present study includes only two white-seeded varieties: Philippine White, with greenish-white seed coats which weather to yellowish-white; and the Pearl variety, with seed coats usually "lilacy" white, also weathering to yellowish-white. Among the white-seeded hybrid strains the colors range through snow white, sky-colored white, purplish-tinted white, "lilacy" white, milk-white, yellowish-white, greenish-white, and fleshy-white. The last-named may sometimes, by casual observation, be classed as pale flesh, but otherwise the whites are easily separated from the other color groups.

The Pearl variety came to the writer in 1931 in a collection of peanut varieties from a commercial firm with the notation that it was obtained from a farmer near Opelika, Ala. The vine type resembles the Spanish variety very closely, but certain characteristics suggest those of the Valencia variety, which is grown to some extent throughout the South, principally as a roasting nut for home consumption. The characteristics of the Pearl variety suggest that it may have originated as a chance cross between the Valencia and the Spanish varieties. So far the writer has been unable to trace the variety to its original source, and any statement as to origin must be accepted as a tentative guess.

EXPERIMENTAL RESULTS

The results obtained from crossing the Philippine White variety with three varieties (Spanish, Virginia Runner, and North Carolina Runner) having flesh-colored testa are shown in table 1. The genetic constitution of the varieties with flesh-colored testa are indicated by $F_1F_1F_2F_2$ and that of Philippine White by $f_1f_1f_2f_2$. In all three crosses the seed of F_1 plants was flesh and that of F_2 flesh and white in a 15:1 ratio. These results indicate that the three flesh-colored varieties have duplicate genes for flesh color and thus confirm the results reported by Patel, John, and Seshadri (*5*) from crosses (Philippine White × Saloum and Philippine White × Gudiyattam) involving the same colors.

TABLE 1.—*Inheritance of flesh-colored testa*

Parents		F_2 phenotypes [1]		χ^2	P
Flesh $F_1F_1F_2F_2$	White $f_1f_1f_2f_2$	*Flesh*	*White*		
Spanish, I. W. × Philippine White:					
Observed distribution		73	5		
Expected 15:1 ratio		73	5	0.0034	0.95+
Virginia Runner × Philippine White:					
Observed distribution		61	5		
Expected 15:1 ratio		62	4	.1980	.7−
North Carolina Runner × Philippine White:					
Observed distribution		43	2		
Expected 15:1 ratio		42	3	.2504	.7−
Total observed		177	12		
Expected 15:1 ratio		177	12	.0032	.95+

[1] F_1 phenotype, all flesh.

The results obtained from crosses involving three varieties with red and seven with flesh-colored testa are shown in table 2. In every case red is dominant to flesh, with a single factor difference, confirming results reported by Van der Stok (*6*), Hayes (*1*), Stokes and Hull (*7*), and Patel and his coworkers (*5*).[3] The results are given here principally for comparison with crosses involving Pearl.

TABLE 2.— *Inheritance of red testa*

Parents		F_2 phenotypes [1]		χ^2	P
Red $RRF_1F_1F_2F_2$	Flesh $rrF_1F_1F_2F_2$	Red	Flesh		
Tennessee Red × Virginia Runner:					
Observed distribution		28	9		
Expected 3:1 ratio		28	9	0.0000	0.9+
Tennessee Red × Virginia Bunch:					
Observed distribution		38	14		
Expected 3:1 ratio		39	13	.1026	.7+
Tennessee Red × North Carolina Runner:					
Observed distribution		96	32		
Expected 3:1 ratio		96	32	.0000	1.0
Tennessee Red × West African:					
Observed distribution		54	18		
Expected 3:1 ratio		54	18	.0000	1.0
Tennessee Red × Spanish, I. W.:					
Observed distribution		68	20		
Expected 3:1 ratio		66	22	.2424	.7−
Kimorales × Spanish, No. 167:					
Observed distribution		96	26		
Expected 3:1 ratio		92	30	.8852	.3+
Kimorales × Java P. L.:					
Observed distribution		90	33		
Expected 3:1 ratio		92	31	.2195	.7−
Valencia × H210:					
Observed distribution		18	7		
Expected 3:1 ratio		19	6	.1200	.7+
Total observed distribution		488	159		
Expected 3:1 ratio		485	162	.0624	.8+

[1] F_1 phenotype, all red.

[3] Also V. K. Badami in unpublished thesis, Cambridge University, to which reference was made by Hunter and Leake (*3*, pp. 339–341).

In every cross involving the Pearl variety, except certain backcrosses, the F_1 seeds have red testa. Results from all crosses shown in table 3 indicate that Pearl carries factors for both red and flesh pigments but either lacks factors for expression of color or carries factors that inhibit the development of color. Until we know more about the chemical nature of peanut pigments, it would seem most logical to assume the absence of factors for development of color. With this assumption we must postulate two factors to explain the 15:1 ratio of reds and whites observed in the crosses Pearl × Tennessee Red and Pearl × Small Japan; whereas the 3:1 ratio obtained in the cross Pearl × Valencia would indicate a single factor difference and that the Valencia variety lacks one factor for development of color.

TABLE 3.—*Inheritance of testa color in crosses involving the Pearl variety*

Parents (variety, composition, and testa color)	F_2 phenotypes [1]			χ^2	P
	Red	Flesh	White		
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × Philippine White $rrf_1f_1f_2f_2D_1D_1D_2D_2$ (white):					
Observed distribution	98	16	5		
Expected 675:225:124 ratio	79	26	14	15.0121	0.01–
Expected 720:225:79 ratio	84	26	9	8.2973	.02–
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × Virginia Runner $rrF_1F_1F_2F_2D_1D_1D_2D_2$ (flesh):					
Observed distribution	338	89	26		
Expected 45:15:4 ratio	319	106	28	4.1566	.1+
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × North Carolina Runner $rrF_1F_1F_2F_2D_1D_1D_2D_2$ (flesh):					
Observed distribution	366	108	29		
Expected 45:15:4 ratio	354	118	31	1.4489	.5–
Total observed distribution	704	197	55		
Expected 45:15:4 ratio	672	224	60	5.1530	.1–
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × Tennessee Red $RRF_1F_1F_2F_2D_1D_1D_2D_2$ (red):					
Observed distribution	44		3		
Expected 15:1 ratio	44		3	.0015	.95+
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × Small Japan $RRF_1F_1F_2F_2D_1D_1D_2D_2$ (red):					
Observed distribution	401		33		
Expected 15:1 ratio	407		27	1.3573	.2+
Pearl $RRF_1F_1F_2F_2d_1d_1d_2d_2$ (white) × Valencia $RRF_1F_1F_2F_2D_1D_1d_2d_2$ (red):					
Observed distribution	42		16		
Expected 3:1 ratio	44		14	.2069	.7–

[1] F_1 phenotype, all red.

From the results obtained in crossing Philippine White with several other varieties, including those with purple, red, and "rose" (flesh) seed coats, Patel et al. (*5*) reached the conclusion that the Philippine White variety carries no factor for seed coat color; also that the presence of "rose" (flesh) pigment is necessary for the expression of either red or purple color. The results from crossing this variety with Pearl are, therefore, of special interest. In the crosses Pearl×Philippine White and reciprocal, the testa of the zygote is white, the shade of the pistillate parent, that of seed from F_1 plants is red, Indian lake to vinous purple, and that from F_2 seed red, flesh, and white. While the Philippine White variety lacks both red and flesh pigment, it

does, apparently, carry factors for development of color, and we may express the genetic constitution as $rrf_1f_1f_2f_2D_1D_1D_2D_2$ and that of the Pearl variety as $RRF_1F_1F_2F_2d_1d_1d_2d_2$. Assuming the presence of a flesh factor necessary for expression of red, the expected ratio would be 675:225:124, red, flesh, and white, respectively. If flesh pigment is not necessary for the expression of red, the ratio would be 720:225:79. The observed ratio agrees somewhat better with the latter assumption, yet other evidence for the assumption that flesh is necessary for the development of red color is so strong that it seems safer to explain otherwise the poor agreement of the observed with the expected ratio.

The total number of progenies observed is too small to give a very close approximation of the expected ratio when so many factors are involved. Furthermore, the Philippine White variety produces, at least under the conditions of the present study, a very high percentage of chaffy, nonviable seed. In the hybrid stocks this characteristic is accentuated, many plants producing no seed at all. A lethal (albino) factor is also involved in this cross, but the records do not justify any attempt to correlate this factor with the ratios obtained. However, the fact that reds are in excess in this cross and also in the cross Pearl×Virginia Runner suggests the possible correlation of lack of pigment with unfruitfulness and with nonviability of seed.

In the F_3 and succeeding generations various red phenotypes were observed, producing all red, red and flesh, red and white, and red, flesh, and white in various ratios; but the number of F_3 families was too small to include all genotypes. The flesh bred true or gave flesh and white. The whites always bred true.

If the assumed genetic constitution of the Pearl and the Philippine White varieties is correct, we should expect two classes of whites in the F_2 and succeeding progenies; i. e., those with factors for pigmentation but lacking factors for development of color and those lacking factors for pigment.

Results obtained with one red-seeded F_2 selection, H220–13, from this cross indicates the presence of the two classes of whites and also gives very substantial evidence that the presence of the flesh pigment factor is necessary for development of red color. In this selection the seed of the F_2 plant was red. In the F_3, 48 plants produced red seed and 18 produced white, none flesh. Plants from each of the white sibs were backcrossed to Pearl and the same plants crossed also with North Carolina Runner. Unfortunately, mice destroyed many of the seeds before maturity. However, seed was obtained from 13 sibs with Pearl and from 9 with North Carolina Runner. All the crosses with North Carolina Runner produced red seed in the F_1 generation, indicating that all these whites carried the factor for red pigment. Eight of the 13 sibs when crossed with Pearl also produced one or more F_1 plants with red seed, indicating that they carried at least one factor for development of color.

From the assumed genetic constitution of the parents there are three possible genotypes that would approximate the 48 red and 18 white segregation of H220–13.

		Red	White	
1	$RRF_1F_1F_2F_2D_1d_1d_2d_2$ or $RRF_1F_1F_2F_2d_1d_1D_2d_2$	3	1	all whites like Pearl.
2	$RRf_1f_1F_2f_2D_1d_1d_2d_2$ or $RRF_1f_1F_2f_2d_1d_1D_2d_2$	45 or 3	19 1	3 whites not like Pearl. assuming red independent of flesh.
3	$RRf_1f_1f_2f_2D_1d_1D_2d_2$ or $RRf_1f_1F_2f_2D_1d_1D_2d_2$	45 or 15	19 1	15 whites not like Pearl. assuming red independent.
Observed distribution		48	18	χ^2 P
Expected 3:1 ratio		49.5	16.5	0.1818 0.7–
Expected 45:19 ratio		46.4	19.6	.1901 .7–

The observed ratio is evidently not near 15:1 under proposition 3. The 3:1 ratio gives a slightly lower χ^2 value than the 45:19 ratio, but in both cases where the 3:1 ratio is obtained all the whites are like Pearl, lacking factors for expression of color, and could not give red testa when crossed with Pearl. Since all produced red seed coats when crossed with North Carolina Runner and more than half of the sibs gave red when crossed with Pearl, we are forced to the assumption that the factor for red was present in all but in some the color did not develop because of the absence of the developer factor and in others because of the absence of flesh pigment. The results also indicate that presence of the flesh factor is necessary for expression of red color and that the genetic constitution of H220–13 was either $RRF_1f_1f_2f_2D_1d_1D_2d_2$ or $RRf_1f_1F_2f_2D_1d_1D_2d_2$.

In the crosses between Pearl and the varieties with flesh seed coats the above white genotype lacking factors for flesh pigment would not be obtained. All whites would be homozygous for flesh pigment, and three fourths would have the factor for red; but all would lack factors for color development. Along with the above series of crosses seven white-seeded selections from the cross Pearl × Virginia Runner were backcrossed to Pearl and four of these were also crossed with North Carolina Runner. In all seven crosses with Pearl the F_1 progenies produced white seed and all four crossed with North Carolina Runner produced red seed in F_1, indicating that the selections were of the Pearl genotype.

Records of seed-coat color were obtained for 118 F_3 families from the Pearl × Virginia Runner and Pearl × North Carolina Runner crosses. As shown in table 4, this number apparently included all possible genotypes. Approximately half the recorded families were selected because of resistance to disease, high yield, and other characteristics desirable for a peanut variety. For this reason, there was conscious preference for strains with flesh-colored seed coats; yet the observed distribution of families among the various genotypes is in fairly close agreement with the expected: $\chi^2=11.2149$, $P=0.3$.

TABLE 4.—*F_2 genotypes and F_3 distribution of phenotypes from crosses Pearl × Virginia Runner and Pearl × North Carolina Runner*

Number in 64	F_2 genotypes	Color of F_2	Number of families observed	F_3 distribution			χ^2	P
				Red	Flesh	White		
1	$RRF_1F_1F_2F_2D_1D_1D_2D_2$	Red	14	(1)				
2	$RRF_1F_1F_2F_2D_1D_1D_2d_2$							
2	$RRF_1F_1F_2F_2D_1d_1D_2D_2$							
1	$RRF_1F_1F_2F_2D_1D_1d_2d_2$			(1)				
1	$RRF_1F_1F_2F_2d_1d_1D_2D_2$							
4	$RRF_1F_1F_2F_2D_1d_1D_2d_2$	do	11	15		1		
				670		50	0.5926	0.5—
2	$RRF_1F_1F_2F_2D_1d_1d_2d_2$	do	6	3		1		
2	$RRF_1F_1F_2F_2d_1d_1D_2d_2$			286		86	.7025	.5—
2	$RrF_1F_1F_2F_2D_1D_1D_2D_2$	do	25	3	1			
4	$RrF_1F_1F_2F_2D_1D_1D_2d_2$			1,266	399		.9532	.3
2	$RrF_1F_1F_2F_2D_1D_1d_2d_2$							
2	$RrF_1F_1F_2F_2d_1d_1D_2D_2$							
8	$RrF_1F_1F_2F_2D_1d_1D_2d_2$	do	13	45	15	4		
				698	251	68	1.3880	.5
4	$RrF_1F_1F_2F_2D_1d_1d_2d_2$	do	7	9	3	4		
4	$RrF_1F_1F_2F_2d_1d_1D_2d_2$			348	105	145	.9900	.7—
1	$rrF_1F_1F_2F_2D_1D_1D_2D_2$	Flesh	14		(1)			
2	$rrF_1F_1F_2F_2D_1D_1D_2d_2$							
2	$rrF_1F_1F_2F_2F_1d_1D_2D_2$							
1	$rrF_1F_1F_2F_2D_1D_1d_2d_2$							
1	$rrF_1F_1F_2F_2d_1d_1D_2D_2$							
4	$rrF_1F_1F_2F_2D_1d_1D_2d_2$	do	6	15		1		
				289		18	.0784	.8—
2	$rrF_1F_1F_2F_2D_1d_1d_2d_2$	do	13	3		1		
2	$rrF_1F_1F_2F_2d_1d_1D_2d_2$			604		202	.0017	.95+
1	$RRF_1F_1F_2F_2d_1d_1d_2d_2$	White	8					
2	$RrF_1F_1F_2F_2d_1d_1d_2d_2$					(1)		
1	$rrF_1F_1F_2F_2d_1d_1d_2d_2$							

[1] All.

SUMMARY AND CONCLUSIONS

By the use of color standards the testa color of 85 varieties and strains of peanuts, as well as of hybrid progenies from crosses among these varieties, were separated into three color groups, red, flesh, and white. A fourth color, dark purple, as reported by Patel et al. (*5*) for the Corientes-3 variety, is not included in this study.

Flesh-colored testa is dominant to genetically pure white with a bigenic difference, indicating that all the flesh-colored varieties so far studied, both bunch and runner types, have two identical genes for color.

Red testa is dominant to flesh with a single factor difference, but the flesh pigment is necessary for expression of red color.

Two varieties with white seed coats were found to differ in their genetic constitution. Apparently the Pearl variety carries factors for both red and flesh pigment but lacks factors for expression of color, while the Philippine White has neither pigment but does carry factors for development of color.

LITERATURE CITED

(1) HAYES, T. R.
1933. THE CLASSIFICATION OF GROUNDNUT VARIETIES. WITH A PRELIMINARY NOTE ON THE INHERITANCE OF SOME CHARACTERS. Trop. Agr. West Indies 10: 318–327, illus.

(2) HULL, FRED H.
1937. INHERITANCE OF REST PERIOD OF SEEDS AND CERTAIN OTHER CHARACTERS IN THE PEANUT. Fla. Agr. Expt. Sta. Bul. 314, 46 pp., illus.

(3) HUNTER, H., and LEAKE, H. MARTIN.
1933. RECENT ADVANCES IN AGRICULTURAL PLANT BREEDING. 361 pp., illus. London.

(4) OBERTHÜR, RENÉ, and others.
1905. RÉPERTOIRE DE COULEURS POUR AIDER À LA DÉTERMINATION DES COULEURS DES FLEURS, DES FEUILLAGES ET DES FRUITS. Société Française des Chrysanthémistes, 3 v., illus. Paris.

(5) PATEL, J. S., JOHN, C. M., and SESHADRI, C. R.
1936. THE INHERITANCE OF CHARACTERS IN THE GROUNDNUT ARACHIS HYPOGAEA. Indian Acad. Sci. Proc. 3 (B): 214–233, illus.

(6) STOK, J. E. VAN DER.
1910. MEDEDEELINGEN OMTRENT KRUISINGSPROEVEN. Teysmannia 21: [118]–124.

(7) STOKES, W. E., and HULL, FRED H.
1930. PEANUT BREEDING. Amer. Soc. Agron. Jour. 22: 1004–1019.

EFFECTIVENESS OF HEAT PENETRATION IN MEAT CANNED IN GLASS JARS IN A PRESSURE COOKER[1]

By CASPER I. NELSON, *bacteriologist and soil biologist*, and DARLINE KNOWLES, *human nutritionist, North Dakota Agricultural Experiment Station*

INTRODUCTION

It has previously been shown [2] that under conditions prevailing when meat is processed in sealed tin containers and sterilized in a retort under steam pressure the effectiveness of heat penetration and the sterilizing process depend upon five variables; namely, type of pack, amount of steam pressure, size of can, time of processing, and method of cooling. Heat penetration is most rapid when there is least interference with convection currents. Fifteen pounds steam pressure is necessary to obtain sterility in the strict sense of the laboratory. The period required to obtain sterility varies directly with the size of the container.

Other factors being constant and controllable, the type of container used in the home canning of meat may be the factor determining the success of the process. Since glass jars are the containers commonly used in the home and since the rate of heat transference is slower through glass than through tin, this investigation was undertaken to determine the length of the processing period necessary in canning a solid pack of meat in glass jars.

EQUIPMENT AND PROCEDURE

In order that the temperature might be recorded at regular interval throughout the processing period, a 12-quart pressure cooker was modified in the manner first described by Magoon and Culpepper [3] and later by Nelson and Berrigan.[4]

Wide-mouthed, quart-size, glass jars with the mason-type Kerr lids were used to facilitate the soldering of the brass plate to the jar lid.

It was necessary to use a long-stemmed thermometer on which the graduation started 6 inches from the mercury bulb in order that readings might be visible above the top of the retort cover.

The top cut of beef round was used throughout this study. The eye muscle was first sectioned out, and then the rest of the beef was cut into pieces of a size that could be conveniently placed in the jar.

Test cultures of bacteria were sealed in thin-walled, glass ampoules and buried deep in the eye muscle, since previous work [4] had shown this to be a reliable method. This section of the round was then wrapped in a single layer of cheesecloth in order that it might be quickly identified after the processing period.

A glass jar was half filled with meat, the eye muscle containing the test organisms placed in the center, and the remaining space packed

[1] Received for publication May 21, 1940.

[2] NELSON, CASPER I., and BERRIGAN, DOROTHY. EFFECTIVENESS OF HEAT PENETRATION IN THE CANNING OF MEAT IN THE HOME BY THE PRESSURE COOKER. Jour. Agr. Res. 59: 465–474, illus. 1939.

[3] MAGOON, C. A., and CULPEPPER, C. W. A STUDY OF THE FACTORS AFFECTING TEMPERATURE CHANGES IN THE CONTAINER DURING THE CANNING OF FRUITS AND VEGETABLES. U. S. Dept. Agr. Bul. 956, 55 pp., illus. 1921.

[4] See footnote 2.

with portions of the beef round. To maintain as nearly equivalent conditions as possible, the contents of all jars were adjusted to approximately the same weight.

After the jars were packed, they were immersed in boiling water and preheated until the temperature of the center of the pack was 30° C.

Since it had previously been reported [5] that jars may be sealed tight before processing in a pressure cooker, the jar lid which had been soldered to the retort equipment described above was screwed firmly onto the jar. By this arrangement the jar was suspended exactly in the center of the retort. A layer of water about 1 inch deep was maintained in the pressure cooker. After the cooker had been sealed, the pet cock was left open until the air escaped. After the steam pressure had reached 15 pounds, the temperature was recorded at 1-minute intervals. At the end of the processing period the jars were removed from the pressure cooker and allowed to cool to room temperature. Since cooling could not be hastened by immersion of the jars in cold water, as is the usual procedure when tin cans are used, the total sterilizing effect of the processing was prolonged. This was especially marked in the case of the storage jars, since they were tightly sealed before processing and a greater length of time was required to cool them. Usually the broth in these jars boiled for 3 to 5 minutes after the jars were removed from the pressure cooker.

The bacterial cultures used to test the sterilizing process were *Clostridium botulinum*, Type A (in an aged-spore state), *Escherichia coli* (fresh suspension), and *Bacillus mesentericus* (aged-spore state). The bacterial suspensions were prepared in physiological saline solution. Although such a saline solution has been shown to have the effect of reducing the viable count of a bacterial suspension on standing it was not considered that the heavy suspension used would be weakened to the extent of invalidating the results obtained. These suspensions were maintained at uniform turbidity throughout the experiment.

Ampoules from all jars were removed under aseptic conditions and the contents placed in appropriate culture media. Robertson's heart medium was used for culturing *Clostridium botulinum*, lactose fermentation tubes for *Escherichia coli*, and nutrient broth for *Bacillus mesentericus*. All tubes were incubated at 37° C. for a week. Growths were identified by appropriate criteria.

A total of 38 jars of meat were prepared in the manner described, and these were processed over periods of 50, 60, 65, 70, 80, 90, 100, 110, and 120 minutes. At least four jars were prepared at each interval of time; half were opened immediately for bacteriological examination and the other half were stored in an incubator at 25° C. for 6 months.

EXPERIMENTAL DATA

In figures 1 to 4 are depicted curves obtained by plotting time of processing against temperature. The temperature curves shown in figures 1 and 2 were drawn from temperature readings made with an oridnary stock thermometer. Variation was pronounced. Figures 3 and 4 represent the continous use of one especially accurate thermometer. These curves well illustrate the difficulty of checking all

[5] FELLERS, C. R., MACLINN, W. A., and LEVINE, A. S. HOME CANNING RESEARCH. Mass. Agr. Expt. Sta. Bul. 331: 70-71. 1937.

variable factors. The distribution of fat and lean affects the rate of heat penetration. Although all the fat was removed that could be removed, some pieces of the meat contained decidedly more interstitial fat than others. The difficulty of limiting all the variable factors in a study of this type has been clearly pointed out by Lang.[6] A beef pack, however, does not offer such an opportunity for change in

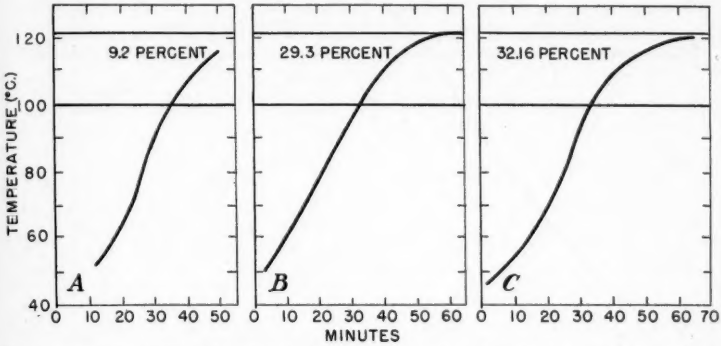

FIGURE 1.—Variations in effective heat penetration (see text for fuller explanation) as affected by length of processing period. Processing periods: *A*, 50 minutes; *B*, 60 minutes; *C*, 65 minutes.

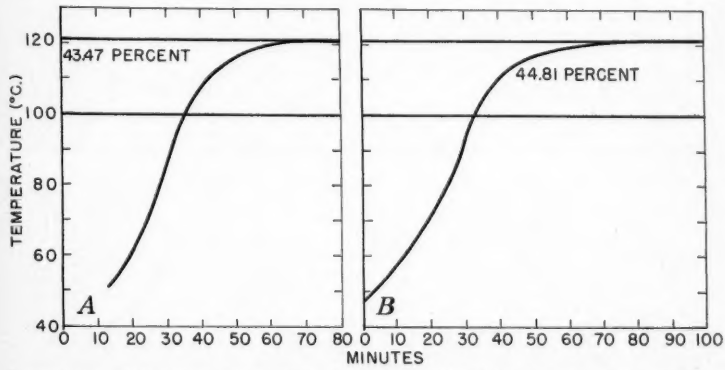

FIGURE 2.—Variations in effective heat penetration (see text for fuller explanation) as affected by length of processing period. Processing periods: *A*, 70 minutes; *B*, 80 minutes.

the fluidity of the pack during processing as do the softer marine foods, and it may safely be assumed that curves will not be broken out of their regularity by major changes in heat convection.

The space between the two heavy horizontal lines on the graphs, drawn at 100° and 120° C., indicates the zone of sterilization. The curves shown were originally produced from temperature data plotted on millimeter squared ruling. Each curve circumscribes a dome-

[6] LANG, O. W. THERMAL PROCESSES FOR CANNED MARINE PRODUCTS. Calif. Univ. Pubs., Pub. Health 182 pp., illus. 1935.

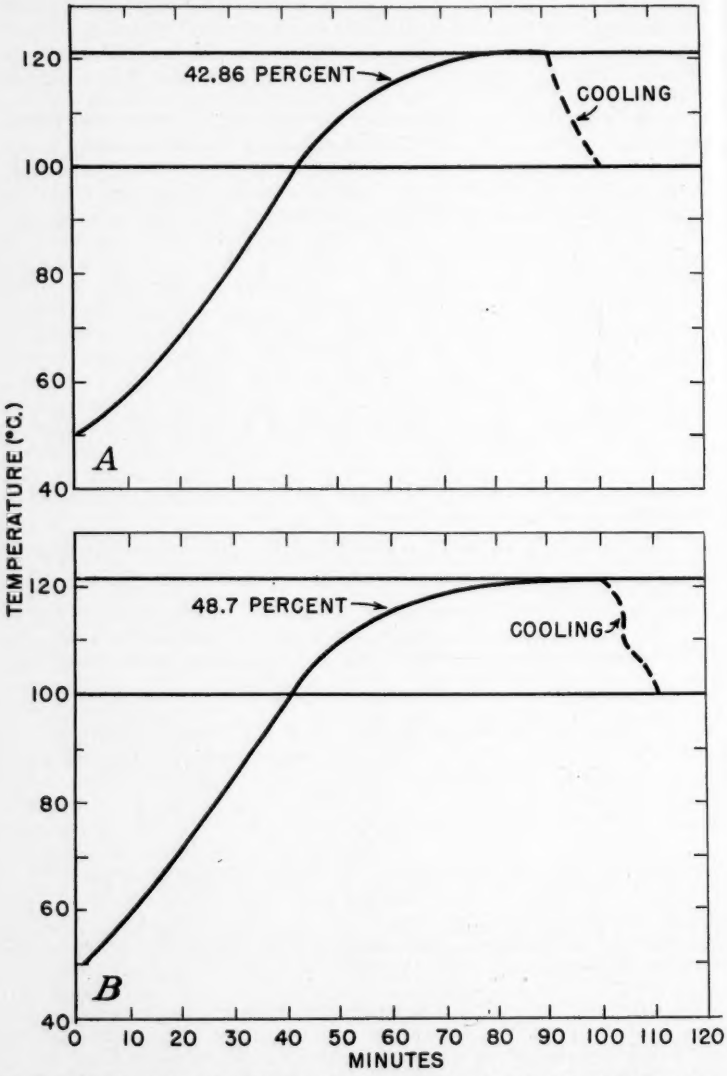

FIGURE 3.—Variations in effective heat penetration (see text for fuller explanation) as affected by length of processing period. Processing periods: *A*, 90 minutes; *B*, 100 minutes.

shaped area that represents sterilization accomplished as a product of time and temperature. The maximum sterilization possible would be represented by an area between the two horizontal lines circumscribed by a temperature curve rising abruptly to 121° at the

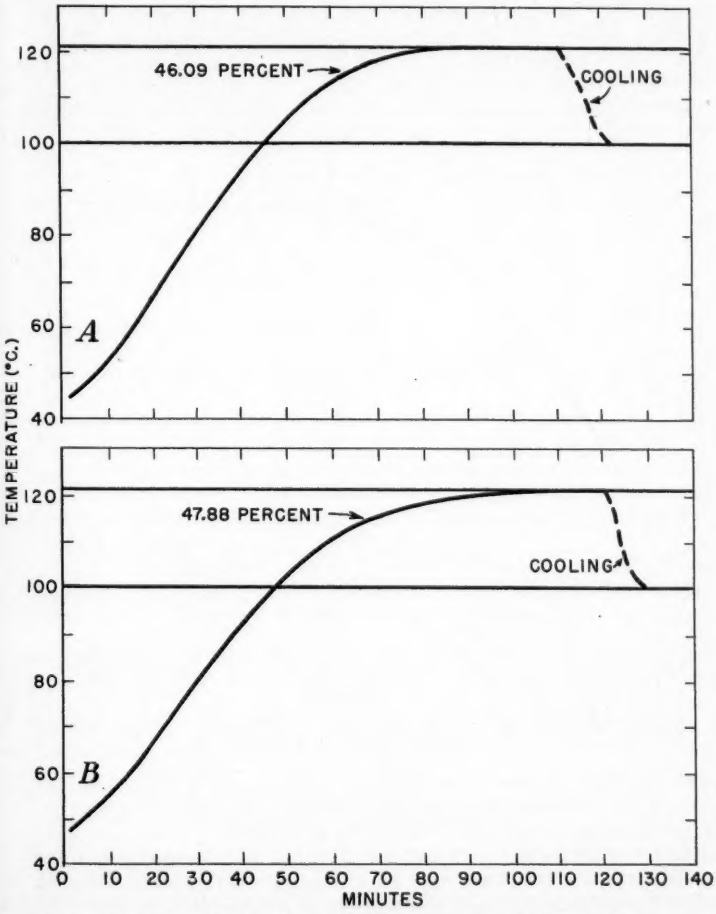

FIGURE 4.—Variations in effective heat penetration (see text for fuller explanation) as affected by length of processing period. Processing periods: *A*, 110 minutes; *B*, 120 minutes.

beginning of the processing. This is observed when water or broth is processed in a tin can.[7]

By accurately computing the area of the space circumscribed under the curve representing the experimental data of a particular processing period and comparing it with the area representing sterilization

[7] See reference given in footnote 2.

of water or broth, a ratio is obtained which expresses the efficiency of sterilization in terms of percent. (The reproduction of the curves in this paper may differ slightly from the curves originally plotted but the percentage holds true.) In figures 5, the averages of efficiencies of heat penetration for each processing period are shown in gradient. The curve reaches its crest at approximately the 90-minute period. This indicates that heat penetration reaches its practical maximum at 15 pounds steam pressure, when quart glass jars are used, in between 80 and 90 minutes after the beginning of the processing. Attainment of maximum efficient heat penetration is not necessarily identical with sterilization efficiency. Heat effective-

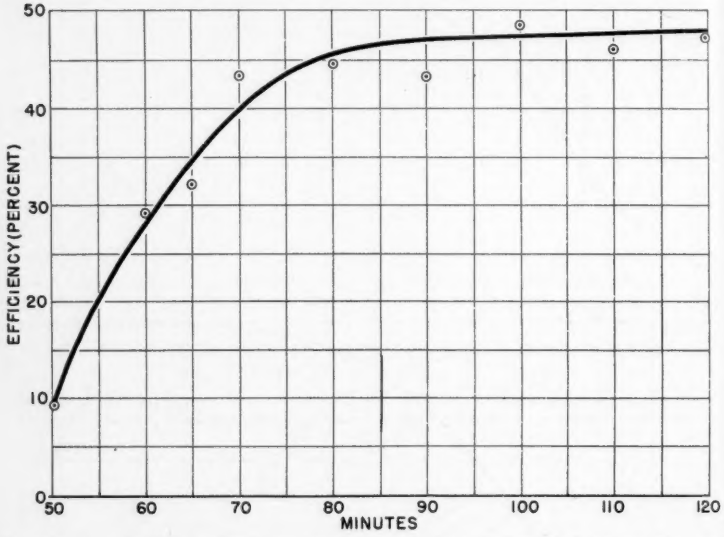

FIGURE 5.—Average percentage efficiency of heat penetration as affected by length of processing period.

ness in killing bacteria can best be determined by exposing the bacteria to the process over the same range of time and temperature used in determining heat penetration and efficiency.

The results obtained from the bacteriological examination of all processed jars are recorded in table 1. The examination of jars opened immediately after processing indicated that (1) the toxigenic anaerobe *Clostridium botulinum* in the spore state was destroyed by processing for 70 minutes at 15 pounds pressure; (2) *Escherichia coli*, a non-spore-forming organism, was destroyed by processing for 70 minutes at 15 pounds pressure (it appeared to be more susceptible to heat than *Clostridium botulinum*), and (3) the spore-bearing, aerobic, soil-inhabiting *Bacillus mesentericus*, in the spore state, was not destroyed during any period of processing tried, up to and including 120 minutes.

TABLE 1.—*Survival of test organisms in jars of meat processed at 15 pounds pressure*

Jars opened immediately					Jars stored				
Jar No.	Processing period	Survival of—			Jar No.	Processing period	Survival of—		
		Clostridium botulinum	*Escherichia coli*	*Bacillus mesentericus*			*Clostridium botulinum*	*Escherichia coli*	*Bacillus mesentericus*
	Minutes					*Minutes*			
14	50	[1] +	0	+	13	50	0	0	0
16	50	+	0	+	15	50	0	0	0
					3 [4]	60	0	0	+
6	60	0	0	+	5	60	0	0	0
8	60	0	0	+	7	60	0	0	0
10	65	+	[2] +	+	9	65	0	0	0
12	65	0	0	+	11	65	0	0	0
					17 [4]	70	0	0	0
18	70	0	0	+	19	70	0	0	0
20	70	0	0	+	37	70	0	0	0
22	80	0	[2] +	+	21	80	0	0	0
24	80	0	0	+	23	80	0	0	+
39	90	0	0	+	25	90	0	0	0
40	90	0	0	+	27	90	0	0	+
41	100	0	0	+	29	100	0	0	0
42	100	0	0	+	31	100	0	0	0
43	110	0	[2] +	+	38	110	0	0	0
44	110	0	0	0 (?)	47	110	0	0	
45	120	0	0	+	33 [3]	120	0	0	+
46	120	0	0	+	35	120	0	0	+

[1] Plus sign indicates survival.
[2] Indications of contamination. In these instances in which *E. coli* appeared to survive, the authors had excellent reason to believe that its presence was not due to survival but to experimental variance. The checks were free from growth. However, at extremes of ranges of viability, it is very possible that heat-resistant individuals might appear.
[3] Leaker.

An examination of the jars stored at 25° C. for 6 months or more showed that (1) *Clostridium botulinum* and *Escherichia coli* had been destroyed in all jars; (2) *Bacillus mesentericus* still persisted in a few. It has been pointed out before that the stored jars necessarily had a more prolonged cooling period, which no doubt increased the sterilizing effect of the processing.

SUMMARY AND CONCLUSION

The results obtained in this study indicate that the maximum point of efficiency in heat penetration in the processing of solid packs of beef in quart glass jars is reached at approximately 90 minutes. This represents a maximum efficiency of less than 50 percent.

The home canning of beef in quart glass jars in a pressure cooker apparently is safe if the pack is preheated to 30° C. and processed 90 minutes at 15 pounds steam pressure.

U. S. GOVERNMENT PRINTING OFFICE: 1941